

DESCRIPTION

LOW-FRICTION SLIDING MECHANISM, LOW-FRICTION AGENT COMPOSITION  
AND METHOD OF FRICTION REDUCTION

5

TECHNICAL FIELD

The present invention relates to; a low-friction sliding mechanism; a low-friction agent composition; a method of friction reduction; a manual transmission; and a final reduction gear unit.

10 In more detail, the present invention relates to; a low-friction sliding mechanism that can improve the friction characteristics of various sliding surfaces in, for instance, internal combustion engines and drive system transmission units; a low-friction agent composition and a method of friction reduction; a manual  
15 transmission that is provided with a sliding section that is small in the friction coefficient and excellent in the seizure resistance and wear resistance and can exhibit excellent fuel cost over a long term; and a final reduction gear unit that can reduce the friction coefficient in a sliding section and improve the seizure  
20 resistance and the wear resistance and reduce the friction resistance to improve the fuel efficiency of an automobile.

BACKGROUND ART

Earth scale environment problems such as global warming and destruction of the ozone layer are largely highlighted. In  
25 particular, the CO<sub>2</sub> reduction that is said to largely affect on the warming of the earth as a whole is gathering attention on how to decide the regulation value in each country.

As to the CO<sub>2</sub> reduction, the reduction of the energy loss due to the friction loss of machines and devices, in particular,  
30 the reduction of the fuel cost of automobiles is a large problem. Accordingly, the roles of sliding materials and lubricants are very important in this connection.

A role of the sliding material is to be excellent in the wear resistance and develop excellent wear resistance to sections of which friction and wear environment are severe among the sliding sections of an engine. Recently, various kinds of hard thin film  
5 materials are being forwarded in applications. The friction coefficients of general DLC materials are lower in air and in the absence of lubricating oil than that of wear resistant hard coating materials such as TiN and CrN; accordingly, these are expected as low friction sliding materials.

10 Furthermore, as an energy saving measure in the lubricating oil, for instance, as a fuel efficiency measure of an engine,  
1) reduction, caused by lowering the viscosity, of the viscous resistance in a hydrodynamic lubrication region and the agitation resistance in an engine and 2) reduction, owing to blending of  
15 an optimum friction modifier and various kinds of additives, of the friction loss under mixed lubrication and boundary lubrication region are proposed. Many researches have been conducted mainly of organic Mo compounds such as MODTC and MoDTP as the friction modifier. In a sliding surface made of an existing steel material,  
20 a lubricating oil composition in which an organic Mo compound that exhibits the excellent low friction coefficient at an early stage of use is advantageously applied.

On the other hand, a general DLC material excellent in the low friction characteristics in air is reported to be, in the  
25 presence of the lubricating oil, low in the friction reduction effect (for instance, non-patent literature 1). Furthermore, it has been found that even when a lubricating oil composition containing an organic molybdenum compound is applied to the sliding material the friction reduction effect cannot be sufficiently exerted (for instance, non-patent literature 2).

Non-patent literature 1: Kano et al., *Proceedings of Japanese Tribology Society*, p.11 to 12, May, 1999 (Tokyo)

Non-patent literature 2: Kano et al., *Proceeding of World*

*Tribology Congress Sep., 2001, p. 342, (Vienna)*

Then, as to the fuel efficient technology of a manual transmission of an automobile, there is a proposal in which the agitation of lubricating oil by a power transfer is avoided or  
5 made very small to inhibit the power transmission efficiency from deteriorating owing to the agitation resistance (for instance, patent literature 1).

Patent literature 1: JP-A-10-166877

On the other hand, as to the lubricating oil that is used  
10 in such a transmission, a lubricating oil composition in which, to lubrication base oil a boron-containing ash-less dispersant, an alkaline-earth metal base detergent and a sulfur base additive are blended is proposed (patent literature 2). Furthermore, gear oil in which, to base oil that is low in a sulfur content and  
15 has predetermined viscosity, primary zinc dithiophosphate, an alkaline earth metal detergent, alkenyl succinic imide having a polybutenyl group having a predetermined molecular weight, a derivative thereof, phosphoric ester amine salt, and a sulfur compound are contained is proposed (patent literature 3).

20 Patent literature 2: JP-A-2003-82377

Patent literature 3: JP-A-11-181463

Furthermore, as to the fuel efficient technology of the final reduction gear unit of an automobile, with an intention of improving the transmission efficiency at a differential gear,  
25 a lubricating oil composition for use in the final reduction gear unit, which contains a phosphorus base extreme pressure agent selected from a specific range, organic acids having a specific structure and a sulfur base extreme pressure agent selected from a specific range in a lubrication base oil, is proposed (patent  
30 literature 4).

Patent literature 4: JP-A-6-200274

Still furthermore, in order to reduce the sliding friction loss between a roller end surface and an inner wheel large guard,

a conical roller bearing where a cone center of an outer diameter surface of a conical roller is displaced from a center axis of the inner wheel and the application of such conical roller bearing to an automobile differential are proposed (patent literature 5 5).

Patent literature 5: JP-A-2000-192951

#### DISCLOSURE OF INVENTION

In the manual transmission described in patent literature 1, as described above, the reduction of the agitation resistance 10 of the lubricating oil is studied. However, an improvement in the performance and fuel efficient due to the reduction of the friction of the sliding sections, in particular, the compatibility between a sliding member and the lubricating oil is not studied.

Furthermore, as to one that concerns lubricating oil alone, 15 the lubricating oil is formed into a constitution as shown in examples of the patent literatures 2 and 3 to improve the wear inhibition, the fatigue life and the friction characteristics between a synchronizer ring and a gear cone. However, in the study, the characteristics of the sliding member are not 20 particularly considered to reduce the friction coefficient.

Furthermore, in the lubricating oil composition for use in the final reduction gear unit, which is described in the patent literature 4, a prescription is studied to improve the transmission efficiency in the gear section. Still furthermore, in the patent 25 literature 5, an improvement in a structure of the conical roller bearing is studied to reduce the friction loss. However, the reduction of the friction of the sliding surface itself and the compatibility between the sliding member and the lubricating oil are not studied.

30 The invention is achieved considering such problems that existing technologies have; and intends to provide a low-friction sliding mechanism, a low-friction agent composition and a friction reduction method that can exert very excellent low friction

characteristics to a sliding surface present under various applications, and, in particular, that have more excellent low friction characteristics than that of a combination of the existing steel material and the organic Mo compound.

5 Furthermore, the invention intends to provide a manual transmission that can reduce the friction coefficient in various kinds of sliding sections in the manual transmission such as bearing sections to improve the seizure resistance and the wear resistance and to reduce the sliding resistance of the respective sections  
10 to contribute in improving the fuel efficiency of an automobile.

Still furthermore, the invention intends to provide a final reduction gear unit that can reduce the friction coefficient in various kinds of sliding sections in the final reduction gear unit such as a section between a back surface of a side gear that  
15 slidably comes into contact through a washer and an internal surface of a differential case to improve the seizure resistance and the wear resistance and to reduce the sliding resistance of the respective sections to contribute in improving the fuel efficiency of an automobile.

20 The inventors, after studying hard to overcome the above problems, found that a combination of sliding members at least one of which is a DLC material and a specific compound shows the friction characteristics very excellent to an extent that cannot be realized from an existing lubrication theory, and thereby come  
25 to completion of the invention.

Furthermore, the inventors found that, when one or both of sliding surfaces that slidingly contact each other are provided thereon with a hard carbon thin film less in hydrogen content, in the presence of a low-friction agent composition, the friction  
30 coefficient can be largely reduced. Furthermore, the inventors found that, in a sliding member covered with such a hard carbon thin film, in order to realize low friction coefficient and to improve the seizure resistance and the wear resistance, an additive

used in the low-friction agent composition affects to no small extent. Thereby, the invention comes to completion.

In the low-friction sliding mechanism according to the invention, when in a sliding surface made of a DLC coated sliding member an oxygen-containing organic compound or an aliphatic amine compound is included, the friction characteristics more excellent than that of an existing combination of a sliding member and a low-friction agent composition can be obtained.

Furthermore, the manual transmission according to the invention reduces the friction coefficients in various kinds of sliding sections such as a bearing section, improves the seizure resistance and the wear resistance, and furthermore reduces the sliding resistance in various sections to contribute to improve the fuel efficiency of an automobile.

Still furthermore, the final reduction gear unit according to the invention reduces the friction coefficient between a back surface of a side gear and an inner surface of a differential case, improves the seizure resistance and the wear resistance, and furthermore reduces the sliding resistance in various sections to contribute to improve the fuel efficiency of an automobile.

#### BRIEF DESCRIPTION OF DRAWINGS

Fig. 1 is a sectional explanatory diagram exemplifying a sliding section covered with a hard carbon thin film in a manual transmission according to the invention;

Fig. 2 is a sectional explanatory diagram exemplifying a sliding section covered with a hard carbon thin film in a final reduction gear unit according to the invention;

Fig. 3 is a schematic diagram showing an example of a pin-on-disc friction test;

Fig. 4 is a perspective view showing a procedure of a cylinder-on-disc reciprocating dynamic friction test that is used in a friction test in an example according to the invention;

Fig. 5 is a graph showing comparing measurement results

of the friction coefficients according to the cylinder-on-disc reciprocating dynamic friction test shown in Fig. 3; and

Fig. 6 is a graph showing comparing measurement results of the friction coefficients according to the cylinder-on-disc reciprocating dynamic friction test shown in Fig. 3.

#### BEST MODE FOR CARRYING OUT THE INVENTION

In what follows, a low-friction sliding mechanism and a low-friction agent composition according to the invention will be more detailed. In the specification, "%" denotes a mass percentage unless otherwise stated.

Such a low-friction sliding mechanism is formed by including a low-friction agent composition between sliding surfaces that the sliding members form when a DLC coated sliding member (A) and a sliding member (B) are slid. As the low-friction agent composition, one that contains at least one kind selected from a group consisting of an oxygen-containing organic compound (C) and an aliphatic amine compound (D) is used. Thereby, the DLC coated sliding member and the sliding member slide each other at the extremely lower friction than ever.

Here, a DLC (Diamond-Like Carbon) material used in the DLC coated sliding member (A) is an amorphous mainly made of carbon element, and a bonding state between carbons is made of both of a diamond structure ( $SP^3$  bond) and a graphite bond ( $SP^2$  bond). Specifically, a-C (amorphous carbon) entirely made of carbon element, a-C: H (hydrogen amorphous carbon) containing hydrogen and MeC partially containing a metal element such as titanium (Ti) or molybdenum (Mo) can be cited. In the low-friction sliding mechanism according to the invention, from a viewpoint of expressing a large friction reduction effect, the DLC material is preferably made of an a-C material that does not contain hydrogen. Furthermore, in the DLC material, with an increase in the hydrogen content, the friction coefficient increases. Accordingly, the hydrogen content is preferably 20 atomic percent or less. Still

furthermore, in order to sufficiently lower the friction coefficient during sliding in the low friction agent composition and to secure more stable sliding characteristics, the hydrogen content is desirably 10 atomic percent or less, more desirably 5 5 atomic percent or less and still more desirably 0.5 atomic percent or less. The DLC material with such a low hydrogen content can be obtained by depositing by use of a PVD method that substantially does not use hydrogen or a hydrogen-containing compound such as a sputtering method or an ion plating method.

10 In this case, in order to reduce an amount of hydrogen in a film, it is desirable not only to use a gas that does not contain hydrogen during the deposition but also, as needs arise, to bake a reaction vessel and a base material holder and to thoroughly cleanse a surface of the base material before deposition.

15 Furthermore, as a base material that is used in the DLC coated sliding member (A), for instance, carburized steel, hardened steel and non-ferrous metals such as aluminum can be used.

As to the surface roughness of the base material before 20 DLC coating, since a film thickness of a hard carbon thin film is rather thin and the surface roughness of a deposited film is largely affected, the surface roughness Ra (center line average roughness) is preferably 0.1  $\mu\text{m}$  or less. That is, when the surface roughness Ra of the base material is such coarse as to exceed 25 0.1  $\mu\text{m}$ , since projections caused from the roughness of the film surface increase local contact pressure with a counterpart, the likelihood of inducing cracking of the film becomes higher.

Furthermore, a constituent material of the sliding member (B) is not particularly restricted. Specifically, metal 30 materials such as ferrous materials, aluminum base materials, magnesium base materials and titanium base materials can be cited. In particular, the ferrous materials, aluminum base materials and magnesium base materials, being readily applicable to sliding

sections of existing machines and devices and able to widely contribute to an energy saving measure in various fields, are preferable.

Still furthermore, as the constituent materials of the 5 sliding member (B), non-metal materials such as resins, plastics and carbon can be used as well.

Furthermore, materials obtained by applying various kinds of thin film coating on the metal materials and non-metal materials are useful as well.

10 The ferrous materials are not particularly restricted. Not only high purity iron, but also various kinds of ferrous alloys (nickel, copper, zinc, chromium, cobalt, molybdenum, lead, silicon or titanium, and ones obtained by arbitrarily combining these) can be used. Specifically, for instance, carburized steel 15 SCM420 or SCr420 (JIS) can be cited.

Furthermore, the aluminum base materials are not particularly restricted. Not only high purity aluminum but also various kinds of aluminum base alloys can be used. Specifically, for instance, a hypoeutectic aluminum alloy containing 4 to 20% 20 silicon (Si) and 1.0 to 5.0% copper or a hypereutectic aluminum alloy can be desirably used. As preferable example of the aluminum alloy, for instance, AC2A, AC8A, ADC12 and ADC14 (JIS) can be cited.

Among the sliding members (B), the metal materials provided 25 with various kinds of coating are not particularly restricted. Specifically, various kinds of metal materials such as metal base materials obtained by applying a thin film of TiN, CrN or the DLC material on a surface of the ferrous materials, aluminum base materials, magnesium base materials or titanium base materials 30 can be cited. Among these, the metal material coated with the DLC material is preferable. Furthermore, the DLC material is preferably the a-C diamond-like carbon that does not contain hydrogen.

Furthermore, from the sliding stability, the surface roughness Ra of each of the DLC coated sliding member (A) and the sliding member (B) (for instance, metal materials or the metal materials coated with various kinds of thin film) is 0.1  $\mu\text{m}$  or 5 less and preferably 0.08  $\mu\text{m}$  or less. When it exceeds 0.1  $\mu\text{m}$ , local scuffing is caused to result in a large increase in the friction coefficient in some cases.

Still furthermore, in the DLC coated sliding member (A), it is preferable that the surface hardness thereof is in the range 10 of Hv1000 to 3500 in the micro-Vickers hardness (10 g load) and a DLC film thickness is in the range of 0.3 to 2.0  $\mu\text{m}$ . When the surface hardness and the thickness of the DLC coated sliding member (A) are outside of the above-mentioned ranges to be less than Hv1000 in the surface hardness and less than 0.3  $\mu\text{m}$  in the thickness, 15 the DLC coated sliding member becomes easily worn, by contrast, when they exceed Hv3500 and 2.0  $\mu\text{m}$ , respectively, it becomes easily peeled, and, when the surface hardness of the ferrous member is outside thereof to be less than HRC45, under high pressure, in some cases, it becomes easier to buckle and peel.

20 In the case of a ferrous material being used in the sliding member (B), the surface hardness thereof is preferably in the range of HRC45 to 60 in Rockwell hardness C-scale. In this case, even under a high surface pressure sliding condition such as substantially 700 MPa like in a cam follower member, the durability 25 of the film can be effectively maintained.

Furthermore, in the case of an aluminum base material being used in the sliding member (B), the surface hardness thereof is preferably in the range of  $H_B$ 80 to 130 in Brinell hardness. When the surface hardness of the aluminum base material is outside 30 of the above range to be less than  $H_B$ 80, the aluminum base material becomes easily worn.

Still furthermore, in the case of a thin film-coated metal material being used in the sliding member (B), in particular,

in the case of the DLC-coated metal material being used, it is preferable that the surface hardness thereof is in the range of Hv1000 to 3500 in the micro-Vickers hardness (10 g load) and a DLC film thickness is in the range of 0.3 to 2.0 µm. When the 5 surface hardness and the thickness thereof are outside of the above-mentioned ranges to be less than Hv1000 in the surface hardness and less than 0.3 µm in the thickness, the abrasion is easily caused, by contrast, when they exceed Hv3500 and 2.0 µm, in some cases, peeling is easily caused.

10 Sliding surfaces made of the DLC coated sliding member (A) and the sliding member (B), as long as these are sliding surfaces where two sliding surfaces come into contact through a low-friction agent composition, can be used without particular restrictions. For instance, sliding sections of internal combustion engines 15 such as 4-cycle engines and 2-cycle engines (for instance, a valve operating system, a piston, a piston ring, a piston skirt, a cylinder liner, a con-rod, a crank shaft, a bearing, a roller bearing, metal, a gear, a chain, a belt, an oil pump and the like), sliding sections of a driving system transmission mechanism (for 20 instance, gear) and a hard disc drive, and other various sliding surfaces where the friction conditions are severe and the low friction properties are demanded are targeted. In the sliding surfaces, when only at least one of the sliding members is DLC-coated and at least one kind selected from the 25 oxygen-containing organic compound and aliphatic amine compound is supplied, more than ever lubricant and extremely excellent low friction characteristics can be effectively obtained.

For instance, as preferable embodiments in a valve operating system of an internal combustion engine, sliding 30 surfaces made of a disc-like shim and a lifter crown surface where the DLC is coated on a substrate of a steel material and a cam lobe that uses a material involving low-alloy chilled iron, carburized steel or tempered carbon steel, and arbitrary

combinations thereof can be cited.

On the other hand, the aforementioned oxygen-containing organic compound (C) in the low-friction sliding mechanism of the invention is not particularly restricted and can be any organic  
5 compound containing oxygen in the molecule. For example, it may be an oxygen-containing organic compound constituted of carbon, hydrogen and oxygen. The oxygen-containing organic compound may contain another element such as nitrogen, sulfur, halogen (fluorine, chlorine etc.), phosphorus, boron, a metal, or the  
10 like. Particularly in view of further reducing the friction in the sliding surfaces of one sliding member (DLC coated sliding member) (A) and the other sliding member (B), there is preferred an oxygen-containing organic compound constituted of carbon, hydrogen and oxygen and containing a hydroxyl group, or a derivative  
15 thereof, in which it is more preferred that two or more hydroxyl groups are contained. Also for the same reason, there is more preferred an oxygen-containing organic compound with a low sulfur content or free from sulfur.

Also a "derivative" used herein is not particularly restricted and can be, for example, a compound obtained by reacting an oxygen-containing organic compound constituted of carbon, hydrogen and oxygen with a nitrogen-containing compound, a phosphorus-containing compound, sulfur or a sulfur-containing compound, a boron-containing compound, a halogen element or a  
25 halogen-containing compound, a metal element, a metal-containing compound (organic or inorganic), or the like.

The aforementioned oxygen-containing organic compound (C) can specifically be a compound containing a hydroxyl group, a carboxyl group, a carbonyl group, an ester bond or an ether bond  
30 (two or more kinds of such group or bond may also be contained), preferably contains one or more kinds of group or bond selected from a hydroxyl group, a carboxyl group, a carbonyl group, and an ester bond, more preferably is an oxygen-containing organic

compound containing one or more kinds of group or bond selected from a hydroxyl group, a carboxyl group and an ester group, further preferably is an oxygen-containing organic compound containing one or more kinds of group selected from a hydroxyl group and  
5 a carboxyl group, and particularly preferably an oxygen-containing organic compound containing one or more hydroxyl groups.

More specific examples of the oxygen-containing organic compound include alcohols (I), carboxylic acids (II), esters (III),  
10 ethers (IV), ketones (V), aldehydes (VI), carbonates (these compounds may further contain one or more kinds of group or bond selected from a hydroxyl group, a carboxyl group, a carbonyl group, an ester bond and an ether bond) (VII), derivatives thereof and an arbitrary mixture thereof.

15 The above-mentioned alcohols (I) are oxygen-containing organic compounds represented by the following general formula (1):



, for example, a compound containing one or more hydroxyl groups.

20 Examples of alcohols (I) are mentioned below:

Monoalcohols (I-1);

Dialcohols (I-2);

Tri and higher polyalcohols (I-3); and

25 Mixtures of one or more selected from the above three kinds of alcohols (I-4).

Monoalcohols (I-1) have one hydroxyl group in the molecule, including, for example, monohydric alkyl alcohols having from 1 to 40 carbon atoms (in which the alkyl group may be linear or branched) such as methanol, ethanol, propanol (1-propanol, 30 2-propanol), butanol (1-butanol, 2-butanol, 2-methyl-1-propanol, 2-methyl-2-propanol), pentanol (1-pentanol, 2-pentanol, 3-pentanol, 2-methyl-1-butanol, 3-methyl-1-butanol, 3-methyl-2-butanol, 2-methyl-2-butanol,

2,2-dimethyl-1-propanol), hexanol (1-hexanol, 2-hexanol,  
 3-hexanol, 2-methyl-1-pentanol, 2-methyl-2-pentanol,  
 2-methyl-3-pentanol, 3-methyl-1-pentanol, 3-methyl-2-pentanol,  
 3-methyl-3-pentanol, 4-methyl-1-pentanol, 4-methyl-2-pentanol,  
 5 2,3-dimethyl-1-butanol, 2,3-dimethyl-2-butanol,  
 3,3-dimethyl-1-butanol, 3,3-dimethyl-2-butanol,  
 2-ethyl-1-butanol, 2,2-dimethylbutanol), heptanol (1-heptanol,  
 2-heptanol, 3-heptanol, 2-methyl-1-hexanol, 2-methyl-2-hexanol,  
 2-methyl-3-hexanol, 5-methyl-2-hexanol, 3-ethyl-3-pentanol,  
 10 2,2-dimethyl-3-pentanol, 2,3-dimethyl-3-pentanol,  
 2,4-dimethyl-3-pentanol, 4,4-dimethyl-2-pentanol,  
 3-methyl-1-hexanol, 4-methyl-1-hexanol, 5-methyl-1-hexanol,  
 2-ethylpentanol), octanol (1-octanol, 2-octanol, 3-octanol,  
 4-methyl-3-heptanol, 6-methyl-2-heptanol, 2-ethyl-1-hexanol,  
 15 2-propyl-1-pentanol, 2,4,4-trimethyl-1-pentanol,  
 3,5-dimethyl-1-hexanol, 2-methyl-1-heptanol,  
 2,2-dimethyl-1-hexanol), nonanol (1-nonanol, 2-nonanol,  
 3,5,5-trimethyl-1-hexanol, 2,6-dimethyl-4-heptanol,  
 3-ethyl-2,2-dimethyl-3-pentanol, 5-methyloctanol, etc.),  
 20 decanol (1-decanol, 2-decanol, 4-decanol,  
 3,7-dimethyl-1-octanol, 2,4,6-trimethylheptanol, etc.),  
 undecanol, dodecanol, tridecanol, tetradecanol, pentadecanol,  
 hexadecanol, heptadecanol, octadecanol (stearyl alcohol, etc.),  
 nonadecanol, eicosanol, heneicosanol, tricosanol, tetracosanol;  
 25 monohydric alkenyl alcohols having from 2 to 40 carbon atoms (in  
 which the alkenyl group may be linear or branched and the double  
 bond may be in any desired position) such as ethenol, propenol,  
 butenol, hexenol, octenol, decenol, dodecenol, octadecenol (oleyl  
 alcohol, etc.); monohydric (alkyl)cycloalkyl alcohols having from  
 30 3 to 40 carbon atoms (in which the alkyl group may be linear or  
 branched, and the alkyl group and the hydroxyl group may be in  
 any desired position) such as cyclopentanol, cyclohexanol,  
 cycloheptanol, cyclooctanol, methylcyclopentanol,

methylcyclohexanol, dimethylcyclohexanol, ethylcyclohexanol,  
propylcyclohexanol, butylcyclohexanol, dimethylcyclohexanol,  
cyclopentylmethanol, cyclohexylethanol (1-cyclohexylethanol,  
2-cyclohexylethanol, etc.), cyclohexylethanol,  
5 cyclohexylpropanol (3-cyclohexylpropanol, etc.),  
cyclohexylbutanol (4-cyclohexylbutanol, etc.)  
butylcyclohexanol, 3,3,5,5-tetramethylcyclohexanol;  
(alkyl)aryl alcohols (in which the alkyl group may be linear or  
branched, and the alkyl group and the hydroxyl group may be in  
10 any desired position) such as phenyl alcohol, methylphenyl alcohol  
(o-cresol, m-cresol, p-cresol), creosol, ethylphenyl alcohol,  
propylphenyl alcohol, butylphenyl alcohol, butylmethylphenyl  
alcohol (3-methyl-6-tert-butylphenyl alcohol, etc.),  
dimethylphenyl alcohol, diethylphenyl alcohol, dibutylphenyl  
15 alcohol (2,6-di-tert-butylphenyl alcohol,  
2,4-di-tert-butylphenyl alcohol, etc.), dibutylmethylphenyl  
alcohol (2,6-di-tert-butyl-4-methylphenyl alcohol, etc.),  
dibutylethylphenyl alcohol (2,6-di-tert-butyl-4-ethylphenyl  
alcohol, etc.), tributylphenyl alcohol  
20 (2,4,6-tri-tert-butylphenyl alcohol, etc.), naphthol  
( $\alpha$ -naphthol,  $\beta$ -naphthol, etc.), dibutynaphthol  
(2,4-di-tert-butyl- $\alpha$ -naphthol,  
etc.);  
6-(4-hydroxy-3,5-di-tert-butylanilino)-2,4-  
bis(n-octylthio)-1,3,5-triazine, and their mixtures.

25 Of those, more preferred are linear or branched alkyl or  
alkenyl alcohols having from 12 to 18 carbon atoms such as oleyl  
alcohol and stearyl alcohol, in that they may more effectively  
lower the friction of the sliding surfaces formed of the DLC coated  
sliding member (A) and any other sliding member (B) and that they  
30 are poorly volatile and therefore may exhibit their  
friction-reducing effect even at high temperature conditions (for  
example, sliding condition in an internal combustion engine).

Dialcohols (I-2) are concretely those having two hydroxyl

groups in the molecule, including, for example, alkyl or alkenyldiols having from 2 to 40 carbon atoms (in which the alkyl or alkenyl group may be linear or branched, the double bond of the alkenyl group may be in any desired position, and the hydroxyl group may also be in any desired position) such as ethylene glycol, diethylene glycol, polyethylene glycol, propylene glycol, dipropylene glycol, polypropylene glycol, neopentyl glycol, 1,3-propanediol, 1,4-butanediol, 1,2-butanediol, 2-methyl-1,3-propanediol, 1,5-pantanediol, 1,6-hexanediol, 2-ethyl-2-methyl-1,3-propanediol, 2-methyl-2,4-pantanediol, 1,7-heptanediol, 2-methyl-2-propyl-1,3-propanediol, 2,2-diethyl-1,3-propanediol, 1,8-octanediol, 1,9-nonanediol, 2-butyl-2-ethyl-1,3-propanediol, 1,10-decanediol, 1,11-undecanediol, 1,12-dodecanediol, 1,13-tridecanediol, 1,14-tetradecanediol, 1,15-heptadecanediol, 1,16-hexadecanediol, 1,17-heptadecanediol, 1,18-octadecanediol, 1,19-nonadecanediol, 1,20-eicosadecanediol; (alkyl)cycloalkanediols (in which the alkyl group may be linear or branched, and the alkyl group and the hydroxyl group may be in any desired position) such as cyclohexanediol, methylcyclohexanediol; dihydric (alkyl)aryl alcohols having from 2 to 40 carbon atoms (in which the alkyl group may be linear or branched, and the alkyl group and the hydroxyl group may be in any desired position) such as benzenediol (catechol, etc.), methylbenzenediol, ethylbenzenediol, butylbenzenediol (p-tert-butylcatechol, etc.) dibutylbenzenediol (4,6-di-tert-butylresorcinol, etc.), 4,4'-thiobis(3-methyl-6-tert-butylphenol), 4,4'-butylidenebis(3-methyl-6-tert-butylphenol), 2,2'-methylenebis(4-methyl-6-tert-butylphenol), 2,2'-thiobis(4,6-di-tert-butylresorcinol), 2,2'-methylenebis(4-ethyl-6-tert-butylphenol), 4,4'-methylenebis(2,6-di-tert-butylphenol),

2,2'-(3,5-di-tert-butylhydroxy)propane,  
4,4'-cyclohexylidenebis(2,6-di-tert-butylphenol);  
p-tert-butylphenol/formaldehyde condensate,  
p-tert-butylphenol/acetaldehyde condensate; and their mixtures.

5 Of those, preferred are ethylene glycol, propylene glycol, neopentyl glycol, 1,4-butanediol, 1,5-pantanediol, neopentyl glycol, 1,6-hexanediol, 2-methyl-2,4-pantanediol, 2-ethyl-2-methyl-1,3-propanediol, 1,7-heptanediol, 1,8-octanediol, 1,9-nonanediol, 1,10-decanediol,  
10 1,11-undecanediol and 1,12-dodecanediol, in that they may more effectively lower the friction at the sliding surfaces of the DLC coated sliding member (A) and of any sliding member (B). In addition, high-molecular-weight hindered alcohols having a molecular weight of at least 300, preferably at least 400 such  
15 as 2,6-di-tert-butyl-4-(3,5-di-tert-butyl-4-hydroxybenzyl)phenyl alcohol are also preferred in that they are hardly volatile even at high temperatures (for example, under sliding condition in internal-combustion engines) and are highly resistant to heat, and they can well exhibit their  
20 friction-reducing effect and can impart excellent antioxidation stability to lubricating oil.

Tri- and higher polyalcohols (I-3) are concretely those having three or more hydroxyl groups. In general, tri- to deca-alcohols, preferably tri- to hexa-alcohols are used.  
25 Examples of these components are trimethylolalkanes such as glycerin, trimethylolethane, trimethylolpropane, trimethylolbutane; as well as erythritol, pentaerythritol, 1,2,4-butanetriol, 1,3,5-pantanetriol, 1,2,6-hexanetriol, 1,2,3,4-butanetetrol, sorbitol, adonitol, arabitol, xylitol,  
30 mannitol; and their polymers or condensates (e.g., glycerindimers to octamers such as diglycerin, triglycerin, tetraglycerin; trimethylolpropane dimers to octamers such as ditrimethylolpropane; pentaerythritol dimers to tetramers such

as dipentaerythritol; sorbitan; condensates such as sorbitol/glycerin condensate (including intramolecular condensates, intermolecular condensates, and self-condensates)).

5 Saccharides such as xylose, arabitol, ribose, rhamnose, glucose, fructose, galactose, mannose, sorbose, cellobiose, mannose, isomaltose, trehalose and sucrose are also usable.

Of those, more preferred are tri to hexa-alcohols such as glycerin, trimethylolalkanes (e.g., trimethylolethane, trimethylolpropane, trimethylolbutane), pentaerythritol, 1,2,4-butanetriol, 1,3,5-pantanetriol, 1,2,6-hexanetriol, 1,2,3,4-butanetetrol, sorbitol, sorbitan, sorbitol/glycerin condensate, adonitol, arabitol, xylitol, mannitol, and their mixtures; and even more preferred are glycerin, trimethylolethane, trimethylolpropane, pentaerythritol, sorbitan and their mixtures. Especially preferred are polyalcohols having an oxygen content of at least 20 %, preferably at least 30 %, more preferably at least 40 %. Polyalcohols that are higher than hexa-alcohols will too much increase the viscosity.

20 The above-mentioned carboxylic acids (II) are compounds represented by the following general formula (2):



, for example, a compound containing one or more carboxyl groups.

Examples of carboxylic acids (II) are mentioned below:

25 Aliphatic monocarboxylic acids (fatty acids) (II-1);

Aliphatic polycarboxylic acids (II-2);

Carbon-cyclic carboxylic acids (II-3);

Heterocyclic carboxylic acids (II-4); and

Mixtures of two or more selected from the above four kinds 30 of carboxylic acids (II-5).

Aliphatic monocarboxylic acids (fatty acids) (II-1) are concretely those having one carboxyl group in the molecule, including, for example, saturated aliphatic monocarboxylic acids

having from 1 to 40 carbon atoms (in which the saturated aliphatic structure may be linear or branched) such as methanoic acid, ethanoic acid (acetic acid), propanoic acid (propionic acid), butanoic acid (butyric acid, isobutyric acid, etc.), pentanoic acid (valeric acid, isovaleric acid, pivalic acid, etc.), hexanoic acid (caproic acid, etc.), heptanoic acid, octanoic acid (caprylic acid, etc.), nonanoic acid (pelargonic acid, etc.), decanoic acid, undecanoic acid, dodecanoic acid (lauric acid, etc.), tridecanoic acid, tetradecanoic acid (myristic acid, etc.), pentadecanoic acid, hexadecanoic acid (palmitic acid, etc.), heptadecanoic acid, octadecanoic acid (stearic acid, etc.), nonadecanoic acid, eicosanoic acid, heneicosanoic acid, docosanoic acid, tricosanoic acid, tetracosanoic acid, pentacosanoic acid, hexacosanoic acid, heptacosanoic acid, octacosanoic acid, nonacosanoic acid, triacontanoic acid; and unsaturated aliphatic monocarboxylic acids having from 1 to 40 carbon atoms (in which the unsaturated aliphatic structure may be linear or branched, and the unsaturated bond may be in any desired position) such as propenoic acid (acrylic acid, etc.), propynoic acid (propiolic acid, etc.), butenoic acid (methacrylic acid, crotonic acid, isocrotonic acid, etc.), pentenoic acid, hexenoic acid, heptenoic acid, octenoic acid, nonenoic acid, decenoic acid, undecenoic acid, dodecenoic acid, tridecenoic acid, tetradecenoic acid, pentadecenoic acid, hexadecenoic acid, heptadecenoic acid, octadecenoic acid (oleic acid, etc.), nonadecenoic acid, eicosenoic acid, heneicosenoic acid, docosenoic acid, tricosenoic acid, tetracosenoic acid, pentacosenoic acid, hexacosenoic acid, heptacosenoic acid, octacosenoic acid, nonacosenoic acid, triacontenoic acid.

Aliphatic polycarboxylic acids (II-2) include saturated or unsaturated aliphatic dicarboxylic acids having from 2 to 40 carbon atoms (in which the saturated aliphatic or unsaturated aliphatic structure may be linear or branched, and the unsaturated bond may be in any desired position) such as ethane-diacid (oxalic

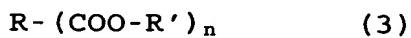
acid), propane-diacid (malonic acid, etc.), butane-diacid (succinic acid, methylmalonic acid, etc.), pentane-diacid (glutaric acid, ethylmalonic acid, etc.), hexane-diacid (adipic acid, etc.), heptane-diacid (pimelic acid, etc.), octane-diacid  
5 (suberic acid, etc.), nonane-diacid (azelaic acid, etc.), decane-diacid (sebacic acid, etc.), propene-diacid, butene-diacid (maleic acid, fumaric acid, etc.), pentene-diacid (citraconic acid, mesaconic acid, etc.), hexene-diacid, heptene-diacid, octene-diacid, nonene-diacid, decene-diacid;  
10 saturated or unsaturated tricarboxylic acids (in which the saturated aliphatic or unsaturated aliphatic structure may be linear or branched, and the unsaturated bond may be in any desired position) such as propane-tricarboxylic acid, butane-tricarboxylic acid, pentane-tricarboxylic acid,  
15 hexane-tricarboxylic acid, heptane-tricarboxylic acid, octane-tricarboxylic acid, nonane-tricarboxylic acid, decane-tricarboxylic acid; and saturated or unsaturated tetracarboxylic acids (in which the saturated aliphatic or unsaturated aliphatic structure may be linear or branched, and  
20 the unsaturated bond may be in any desired position).

Carbon-cyclic carboxylic acids (II-3) are concretely those having one or more carboxyl groups in the carbon-cyclic molecule, including, for example, naphthene ring-having, mono, di, tri or tetracarboxylic acids having from 3 to 40 carbon atoms (in which  
25 the alkyl or alkenyl group, if any therein, may be linear or branched, and the double bond, if any therein, may be in any desired position, and the number and the position of the substituents are not defined) such as cyclohexane-monocarboxylic acid, methylcyclohexane-monocarboxylic acid,  
30 ethylcyclohexane-monocarboxylic acid, propylcyclohexane-monocarboxylic acid, butylcyclohexane-monocarboxylic acid, pentylcyclohexane-monocarboxylic acid,

hexylcyclohexane-monocarboxylic acid,  
heptylcyclohexane-monocarboxylic acid,  
octylcyclohexane-monocarboxylic acid,  
cycloheptane-monocarboxylic acid, cyclooctane-monocarboxylic  
5 acid, trimethylcyclopentane-dicarboxylic acid (camphor acid,  
etc.); aromatic monocarboxylic acids having from 7 to 40 carbon  
atoms such as benzenecarboxylic acid (benzoic acid),  
methylbenzenecarboxylic acid (toluic acid, etc.),  
ethylbenzenecarboxylic acid, propylbenzenecarboxylic acid,  
10 benzenedicarboxylic acid (phthalic acid, isophthalic acid,  
terephthalic acid, etc.), benzenetricarboxylic acid (trimellitic  
acid, etc.), benzeneteracarboxylic acid (pyromellitic acid, etc.),  
naphthalenecarboxylic acid (naphthoic acid, etc.); mono, di, tri  
or tetracarboxylic acids having an aryl group with from 7 to 40  
15 carbon atoms (in which the alkyl or alkenyl group, if any therein  
as a substituent, may be linear or branched and the double bound,  
if any therein, may be in any desired position, and the number  
and the position of the substituents are not defined) such as  
phenylpropanoic acid (hydroatropic acid), phenylpropenoic acid  
20 (atropic acid, cinnamic acid, etc.), salicylic acid,  
alkylsalicylic acid having one or more alkyl groups with from  
1 to 30 carbon atoms.

Heterocyclic carboxylic acids (II-4) are concretely those  
having one or more carboxyl groups in the molecule, including,  
25 for example, those having from 5 to 40 carbon atoms such as  
furanecarboxylic acid, thiophenecarboxylic acid,  
pyridinecarboxylic acid (nicotinic acid, isonicotinic acid,  
etc.).

The above-mentioned esters (III) are compounds represented  
30 by the following general formula (3):



, for example, a compound containing one or more ester bonds.

Examples of esters (III) are mentioned below:

Esters of aliphatic monocarboxylic acids (fatty acids)  
(III-1);

Esters of aliphatic polycarboxylic acids (III-2);

Esters of carbon-cyclic carboxylic acids (III-3);

5       Esters of heterocyclic carboxylic acids (III-4);

Mixtures of any compounds selected from the above five kinds  
of esters (III-5).

Esters of the above III-1 to III-5 may be complete esters  
in which the hydroxyl group and the carboxyl group are all  
10 esterified, or partial esters in which the hydroxyl group or the  
carboxyl group partially remains as such.

The ester of aliphatic monocarboxylic acids (fatty acids)  
(III-1) is an ester of one or more selected from the above-mentioned  
aliphatic monocarboxylic acids (fatty acids) (II-1) and one or  
15 more selected from the above-mentioned mono, di, tri or higher  
polyalcohols (I-1 to I-3). Examples of the esters are aliphatic  
monocarboxylic acids. Concrete examples of the esters are glycerin  
monooleate, glycerin dioleate, sorbitan monooleate, sorbitan  
dioleate, and the like.

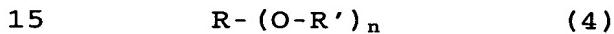
20       The ester of aliphatic polycarboxylic acids (III-2) is an  
ester of one or more selected from the above-mentioned aliphatic  
polycarboxylic acids (II-1) and one or more selected from the  
above-mentioned mono, di, tri or higher polyalcohols (I-1 to I-3).  
Its preferred examples are diesters of one or more polycarboxylic  
25      acid selected from dicarboxylic acids having from 2 to 40,  
preferably from 4 to 18, more preferably from 6 to 12 carbon atoms,  
and one or more selected from monoalcohols having from 4 to 40,  
preferably from 4 to 18, more preferably from 6 to 14, such as  
dibutyl maleate, ditridecyl glutamate, di-2-ethylhexyl adipate,  
30      diisodecyl adipate, ditridecyl adipate, di-2-ethylhexyl sebacate,  
and copolymers of these diesters (e.g., dibutyl maleate) and  
poly- $\alpha$ -olefins having from 4 to 16 carbon atoms; and esters of  
 $\alpha$ -olefin adducts to acetic anhydride or the like, and alcohols

having from 1 to 40 carbon atoms.

The ester of carbon-cyclic carboxylic acids (III-3) is an ester of one or more selected from the above-mentioned carbon-cyclic carboxylic acids (II-3), and one or more selected 5 from the above-mentioned mono, di, tri or higher polyalcohols (I-1 - I-3). Its preferred examples are aromatic carboxylic acid ester such as phthalic acid ester, trimellitic acid ester, pyromellitic acid ester, salicylic acid ester.

10 The ester of heterocyclic carboxylic acids (III-4) is an ester of one or more selected from the above-mentioned heterocyclic carboxylic acids (II-4), and one or more selected from the above-mentioned mono, di, tri or higher polyalcohols (I-1 to I-3).

The above-mentioned ethers (IV) are compounds represented by the following general formula (4):



, for example, a compound containing one or more ether bonds.

Examples of ethers (IV) are mentioned below:

Saturated or unsaturated aliphatic ethers (IV-1);

Aromatic ethers (IV-2);

20 Cyclic ethers (IV-3);

Polyalcoholic esters (IV-4); and

Mixtures of two or more selected from the above three kinds of ethers (IV-5).

Saturated or unsaturated aliphatic ethers (aliphatic 25 monoethers) are concretely saturated or unsaturated aliphatic ethers (IV-1) having from 1 to 40 carbon atoms (in which the saturated or unsaturated aliphatic structure may be linear or branched, and the unsaturated bond may be in any desired position) such as dimethyl ether, diethyl ether, di-n-propyl ether, 30 diisopropyl ether, dibutyl ether, diisobutyl ether, di-n-amyl ether, diisoamyl ether, dihexyl ether, diheptyl ether, dioctyl ether, dinonyl ether, didecyl ether, diundecyl ether, didodecyl ether, ditridecyl ether, ditetradecyl ether, dipentadecyl ether,

dihexadecyl ether, diheptadecyl ether, dioctadecyl ether,  
dinonadecyl ether, dieicosyl ether, methyl ethyl ether, methyl  
n-propyl ether, methyl isopropyl ether, methyl isobutyl ether,  
methyl tert-butyl ether, methyl n-amyl ether, methyl isoamyl ether,  
5 ethyl n-propyl ether, ethyl isopropyl ether, ethyl isobutyl ether,  
ethyl tert-butyl ether, ethyl n-amyl ether, ethyl isoamyl ether,  
divinyl ether, diallyl ether, methyl vinyl ether, methyl allyl  
ether, ethyl vinyl ether, ethyl allyl ether.

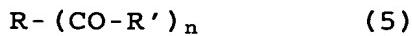
Concretely, aromatic ethers (IV-2) include, for example,  
10 anisole, phenetole, phenyl ether, benzyl ether, phenyl benzyl  
ether,  $\alpha$ -naphthyl ether,  $\beta$ -naphthyl ether, polyphenyl ether,  
perfluoroether; and these may have a saturated or unsaturated  
group (in which the saturated or unsaturated group may be linear  
or branched, and the unsaturated bond may be in any desired position,  
15 and the number and the position of the substituents are not defined).  
Preferably, these are liquid under the service condition thereof,  
especially at room temperature.

Concretely, cyclic ethers (IV-3) are those having from 2  
to 40 carbon atoms, including, for example, ethylene oxide,  
20 propylene oxide, trimethylene oxide, tetrahydrofuran,  
tetrahydropyran, dioxane, glycidyl ether; and these may have a  
saturated or unsaturated group, a carbon ring, or a saturated  
or unsaturated aliphatic group-having carbon ring (in which the  
saturated or unsaturated group may be linear or branched, and  
25 the unsaturated bond may be in any desired position, and the number  
and the position of the substituents are not defined).

Ethers of polyalcohols (IV-4) include one or not less than  
two ethers of one or not less than two polyalcohols selected from  
the above-mentioned dialcohols or trialcohols (I-2 to I-2) or  
30 Monoalcohols. The ethers referred to herein may be complete ethers  
in which all hydroxyl groups of polyalcohols are etherified, or  
partial ethers in which a part of hydroxyl groups remains, in  
which the partial ethers are preferable since they exhibit a low

friction properties.

The ketones (V) are compounds represented by the following general formula (5):



5 , for example, an oxygen-containing organic compound and a compound containing one or more carbonyl bonds.

Specific examples of the aforementioned ketones (V) include:

- a saturated or unsaturated aliphatic ketone (V-1);
- 10 a carbon-ring ketone (V-2);
- a heterocyclic ketone (V-3);
- a ketone alcohol (V-4);
- a ketone acid (V-5); and
- a mixture of two or more selected from ketones of the
- 15 aforementioned five kinds of ketones (V-6).

The saturated or unsaturated aliphatic ketone (V-1) can specifically be a saturated or unsaturated aliphatic ketone with 1 to 40 carbon atoms (which may be linear or ramified or branched and may have an unsaturated bond in an arbitrary position), such 20 as acetone, methyl ethyl ketone, methyl propyl ketone, methyl isopropyl ketone, methyl butyl ketone, methyl isobutyl ketone, pinacolone, diethyl ketone, butyronone, diisopropyl ketone, methyl vinyl ketone, mesityl oxide or methyl heptenone.

Also the carbon-ring ketone (V-2) can specifically be a 25 carbon-ring ketone with 1 to 40 carbon atoms such as cyclobutanone, cyclopentanone, cyclohexanone, acetophenone, propiophenone, butyrophenone, valerophenone, benzophenone, dibenzylketone or 2-acetonaphthone, which may have a saturated or unsaturated aliphatic group (that may be linear or ramified, arbitrary in 30 the position of an unsaturated bond and also arbitrary in the position and number of substitution).

Also the heterocyclic ketone (V-3) can specifically be a carbocyclic ketone with 1 to 40 carbon atoms such as acetothienone

or 2-acetofuron, which may have a saturated or unsaturated aliphatic group (that may be linear or ramified, arbitrary in the position of an unsaturated bond and also arbitrary in the position and number of substitution).

5       Also the ketone alcohol (ketol) (V-4) can specifically be a ketone alcohol with 1 to 40 carbon atoms such as acetol, acetoin, acetoethyl alcohol, diacetone alcohol, phenacyl alcohol or benzoin, which may have a carbon ring or a hetero ring (heterocycle) or may have a carbon ring or a hetero ring having a saturated  
10      or unsaturated aliphatic group (that may be linear or ramified, arbitrary in the position of an unsaturated bond and also arbitrary in the position and number of substitution).

15      Also the ketone acid (V-5) can specifically be a ketone acid with 1 to 40 carbon atoms for example an  $\alpha$ -ketone acid such as piruvic acid, benzoylformic acid, or phenylpiruvic acid, a  $\beta$ -ketone acid such as acetoacetic acid, propionylacetic acid or benzoylacetic acid, or a  $\gamma$ -ketone acid such as levulinic acid or  $\beta$ -benzoylpropionic acid.

20      The aldehydes (VI) are oxygen-containing organic compounds represented by the following general formula (6):



, for example, a compound having one or two aldehyde groups.

Specific examples of the aforementioned aldehydes include (VI) :

25      a saturated or unsaturated aliphatic aldehyde (V1-1);  
          a carbon-ring aldehyde (V1-2);  
          a heterocyclic aldehyde (V1-3); and  
          a mixture of two or more selected from the aldehydes of the aforementioned three kinds of aldehydes (V1-4).

30      The saturated or unsaturated aliphatic aldehyde (V1-1) can specifically be a saturated or unsaturated aliphatic aldehyde with 1 to 40 carbon atoms (such saturated or unsaturated aliphatic structure may be linear or ramified with an arbitrary position

in an unsaturated bond) such as formaldehyde, acetaldehyde, propionaldehyde, butyl aldehyde, isobutyl aldehyde, valeric aldehyde, isovaleric aldehyde, pivalic aldehyde, caproic aldehyde, heptonic aldehyde, capryl aldehyde, peralgonic aldehyde, capric aldehyde, undecyl aldehyde, lauric aldehyde, tridecyl aldehyde, myristic aldehyde, pentadecyl aldehyde, palmitic aldehyde, margaric aldehyde, stearic aldehyde, acrolein, crotonic aldehyde, propionic aldehyde, glyoxal or succinic aldehyde.

The carbon-ring aldehyde (v1-2) can specifically be a  
10 carbon-ring aldehyde with 1 to 40 carbon atoms such as benzaldehyde,  
o-toluic aldehyde, m-toluic aldehyde, p-toluic aldehyde, salicyl  
aldehyde, cinnamic aldehyde,  $\alpha$ -naphthoic aldehyde, or  $\beta$ -naphthoic  
aldehyde, which may have a saturated or unsaturated aliphatic  
group (that may be linear or ramified, arbitrary in the position  
15 of an unsaturated bond and also arbitrary in the position and  
number of substitution).

The heterocyclic aldehyde (V1-3) can specifically be a heterocyclic aldehyde with 1 to 40 carbon atoms such as furfural, which may have a saturated or unsaturated aliphatic group (that may be linear or ramified, arbitrary in the position of an unsaturated bond and also arbitrary in the position and number of substitution).

The carbonates (V11) are oxygen-containing organic compounds represented by the following general formula (7):

$$R - (O-COO-R')_n \quad (7)$$

, for example, a compound having one or two carbonate bonds.

The carbonates (VII) can specifically be a carbonate with 1 to 40 carbon atoms having a saturated or unsaturated aliphatic group, a carbon-ring group, a carbon-ring group having a saturated or unsaturated aliphatic group, or a saturated or unsaturated aliphatic group having a carbon-ring group (such saturated or unsaturated aliphatic group being linear or ramified, arbitrary in the position of an unsaturated bond and also arbitrary in the

position and number of substitution), such as dimethyl carbonate, diethyl carbonate, di-n-propyl carbonate, diisopropyl carbonate, di-n-butyl carbonate, diisobutyl carbonate, di-tert-butyl carbonate, dipentyl carbonate, dihexyl carbonate, diheptyl 5 carbonate, dioctyl carbonate, dinonyl carbonate, didecyl carbonate, diundecyl carbonate, didodecyl carbonate, ditridecyl carbonate, ditetradecyl carbonate, dipentadecyl carbonate, dihexadecyl carbonate, diheptadecyl carbonate, dioctadecyl carbonate, or diphenyl carbonate, or a hydroxy(poly)oxyalkylene 10 carbonate formed by adding an alkylene oxide to such carbonate.

On the other hand, R and R' in the general formula (1) - (7) each independently represents a hydrocarbon group such as an alkyl group, an alkenyl group, an alkylene group, a cycloalkyl group, an alkylcycloalkyl group, an aryl group, an alkylaryl group, 15 or an arylalkyl group (such hydrocarbon group may further contain one or more kinds of group or bond selected from a hydroxyl group, a carboxyl group, a carbonyl group, an ester bond and an ether bond, and may further contain an element other than carbon, hydrogen and oxygen, such as nitrogen or sulfur (for example a heterocyclic 20 compound), a halogen (such as fluorine or chlorine), phosphorus, boron or a metal.

The hydrocarbon group is not particularly restricted in the number of carbon atoms, but preferably has 1 to 40 carbon atoms, more preferably 2 to 30 carbon atoms and particularly 25 preferably 3 to 20 carbon atoms.

Examples of the alkyl group include an alkyl group with 1 to 40 carbon atoms such as a methyl group, an ethyl group, an n-propyl group, an isopropyl group, an n-butyl group, an isobutyl group, a sec-butyl group, a tert-butyl group, a linear or ramified 30 pentyl group, a linear or ramified hexyl group, a linear or ramified heptyl group, a linear or ramified octyl group, a linear or ramified nonyl group, a linear or ramified decyl group, a linear or ramified undecyl group, a linear or ramified dodecyl group, a linear or

ramified tridecyl group, a linear or ramified tetradecyl group, a linear or ramified pentadecyl group, a linear or ramified hexadecyl group, a linear or ramified heptadecyl group, a linear or ramified octadecyl group, a linear or ramified nonadecyl group,  
5 a linear or ramified icosyl group, a linear or ramified henicosyl group, a linear or ramified docosyl group, a linear or ramified tricosyl group, or a linear or ramified tetracosyl group, preferably an alkyl group with 2 to 30 carbon atoms and particularly preferably an alkyl group with 3 to 20 carbon atoms.

10 Examples of the alkenyl group include an alkenyl group with 2 to 40 carbon atoms such as a vinyl group, a linear or ramified propenyl group, a linear or ramified butenyl group, a linear or ramified pentenyl group, a linear or ramified hexenyl group, a linear or ramified heptenyl group, a linear or ramified octenyl  
15 group, a linear or ramified nonenyl group, a linear or ramified decenyl group, a linear or ramified undecenyl group, a linear or ramified dodecenyl group, a linear or ramified tridecenyl group, a linear or ramified tetradecenyl group, a linear or ramified pentadecenyl group, a linear or ramified hexadecenyl group, a linear or ramified heptadecenyl group, a linear or ramified octadecenyl group, a linear or ramified nonadecenyl group, a linear or ramified dicosenyl group, a linear or ramified henicosenyl group,  
20 a linear or ramified docosenyl group, a linear or ramified tricosenyl group, or a linear or ramified tetracosenyl group, preferably an alkenyl group with 2 to 30 carbon atoms and particularly preferably an alkenyl group with 3 to 20 carbon atoms.  
25

Examples of the cycloalkyl group include a cycloalkyl group with 3 to 40 carbon atoms such as a cyclopentyl group, a cyclohexyl group, a cycloheptyl group or a cyclooctyl group, preferably a  
30 cycloalkyl group with 3 to 20 carbon atoms and particularly preferably a cycloalkyl group with 5 to 8 carbon atoms.

Examples of the alkylcycloalkyl group include an alkylcycloalkyl group with 4 to 40 carbon atoms such as a

methylcyclopentyl group, a dimethylcyclopentyl group (including all structural isomers), a methylethylcyclopentyl group (including all structural isomers), a diethylcyclopentyl group (including all structural isomers), a methyl cyclohexyl group,  
5 a dimethylcyclohexyl group (including all structural isomers), a methylethylcyclohexyl group (including all structural isomers), a diethylcyclohexyl group (including all structural isomers), a methylcycloheptyl group, a dimethylcycloheptyl group (including all structural isomers), a methylethylcycloheptyl group  
10 (including all structural isomers), or a diethylcycloheptyl group (including all structural isomers), preferably an alkylcycloalkyl group with 5 to 20 carbon atoms, particularly preferably an alkylcycloalkyl group with 6 to 12 carbon atoms.

Examples of the aryl group include an aryl group with 6  
15 to 20 carbon atoms such as a phenyl group or a naphthyl group, preferably an aryl group with 6 to 10 carbon atoms.

Examples of the alkylaryl group include an alkylaryl group with 7 to 40 carbon atoms for example a mono-substituted phenyl group such as a tolyl group (including all structural isomers),  
20 an ethylphenyl group (including all structural isomers), a linear or ramified propylphenyl group (including all structural isomers), a linear or ramified butylphenyl group (including all structural isomers), a linear or ramified pentylphenyl group (including all structural isomers), a linear or ramified hexylphenyl group  
25 (including all structural isomers), a linear or ramified heptylphenyl group (including all structural isomers), a linear or ramified octylphenyl group (including all structural isomers), a linear or ramified nonylphenyl group (including all structural isomers), a linear or ramified decylphenyl group (including all  
30 structural isomers), a linear or ramified undecylphenyl group (including all structural isomers), or a linear or ramified dodecylphenyl group (including all structural isomers); or an aryl group having two more, same or different linear or ramified

alkyl groups such as a xylyl group (including all structural isomers), a diethylphenyl group, a dipropylphenyl group, a 2-methyl-6-tert-butylphenyl group, a 2,6-di-tert-butyl-4-methylphenyl group, or a 5 2,6-di-tert-butyl-4-(3,5-di-tert-butyl-4-benzyl)phenyl group (alkyl group may further include an aryl group, an alkylaryl group or an arylalkyl group including all structural isomers), preferably an alkylaryl group with 7 to 20 carbon atoms and particularly preferably an alkylaryl group with 7 to 12 carbon 10 atoms.

Also examples of the arylalkyl group include an arylalkyl group with 7 to 40 carbon atoms such as a benzyl group, a phenylethyl group, a phenylpropyl group (including isomers of propyl group), a phenylbutyl group (including isomers of butyl group), a 15 phenylpentyl group (including isomers of pentyl group) or a phenylhexyl group (including isomers of hexyl group), preferably an arylalkyl group with 7 to 20 carbon atoms and particularly preferably an arylalkyl group with 7 to 12 carbon atoms.

Derivatives of the above-mentioned organic 20 oxygen-containing organic compounds (C) can be used like the oxygen-containing organic compounds. Examples of the derivatives are nitrogen-containing compounds, sulfur or sulfur-containing compound, boron-containing compound, halogen elements or halogen element-containing compounds, metal elements or metal-containing 25 compounds (organic or inorganic ones), and compounds obtained by reacting alkylene oxide; however, the derivatives are not limited to the above ones. The derivatives concretely include, for example, compounds prepared by sulfidizing one selected from the above-mentioned alcohols, carboxylic acids, esters and ethers, 30 ketones, aldehydes and carbonates; compounds prepared by halogenating (fluorinating, chlorinating) the same one; its reaction products with acids, such as sulfuric acid, nitric acid, boric acid, phosphoric acid, or their esters or metal salts; and

its reaction products with metals, metal-containing compounds or amine compounds.

Of those, preferred are reaction products of one or more selected from alcohols and carboxylic acids and their derivatives, 5 with amine compounds (e.g., Mannich reaction products, acylated products, amides).

The amine compounds as referred to herein include ammonia, monoamines, diamines, and polyamines. More concretely, their examples are ammonia; alkylamines having an alkyl group with from 10 1 to 30 carbon atoms (in which the alkyl group may be linear or branched) such as methylamine, ethylamine, propylamine, butylamine, pentylamine, hexylamine, heptylamine, octylamine, nonylamine, decylamine, undecylamine, dodecylamine, tridecylamine, tetradecylamine, pentaadecylamine, 15 hexadecylamine, heptadecylamine, octadecylamine, stearylamine, dimethylamine, diethylamine, dipropylamine, dibutylamine, dipentylamine, dihexylamine, diheptylamine, dioctylamine, dinonylamine, didecylamine, diundecylamine, didodecylamine, ditridecylamine, ditetradecylamine, dipentadecylamine, 20 dihexadecylamine, diheptadecylamine, dioctadecylamine, methylethylamine, methylpropylamine, methylbutylamine, ethylpropylamine, ethylbutylamine, and propylbutylamine; alkenylamines having an alkenyl group with from 2 to 30 carbon atoms (in which the alkenyl group may be linear or branched) such 25 as ethenylamine, propenylamine, butenylamine, octenylamine, and oleylamine; alkanolamines having an alkanol group with from 1 to 30 carbon atoms (in which the alkanol group may be linear or branched) such as methanolamine, ethanolamine, propanolamine, butanolamine, pentanolamine, hexanolamine, heptanolamine, 30 octanolamine, nonanolamine, methanolethanolamine, methanolpropanolamine, methanolbutanolamine, ethanolpropanolamine, ethanolbutanolamine, and propanolbutanolamine; alkylenediamines having an alkylene group

with from 1 to 30 carbon atoms, such as methylenediamine, ethylenediamine, propylenediamine, and butylenediamine; polyamines such as diethylenetriamine, triethylenetetramine, tetraethylenepentamine, pentaethylenehexamine; compounds 5 derived from the above-mentioned monoamines, diamines or polyamines and further having an alkyl or alkenyl group with from 8 to 20 carbon atoms, such as undecyldiethylamine, undecyldiethanolamine, dodecyldipropanolamine, 10 oleyldiethanolamine, oleylpropylenediamine, stearyltetraethylenepentamine; heterocyclic compounds such as N-hydroxyethyloleylimidazoline; alkylene oxide adducts of these compounds; and their mixtures.

Of those nitrogen-containing compounds, preferred are aliphatic amines having an alkyl or alkenyl group with from 15 10 to 20 carbon atoms (these may be linear or branched) such as decylamine, dodecylamine, tridecylamine, heptadecylamine, octadecylamine, oleylamine and stearylamine.

Of the derivatives of these oxygen-containing organic compounds, preferred are amides of carboxylic acid having 8 to 20 carbon atoms, of the above-mentioned aliphatic monocarboxylic acids (fatty acids) (II-1) such as oleic amide.

While the oxygen-containing organic compounds have been explained above, those having hydroxyl group is preferable of them because those are excellent in friction reduction effect. 25 Of hydroxyl groups, preferred are alcoholic hydroxyl groups as compared with hydroxyl groups which are directly combined with carbonyl groups such as carboxyl groups. Further, Although the number of such hydroxyl groups in the compound is particularly not limited, it is preferable to have more hydroxyl groups because 30 of being excellent in friction lowering effect. However, there is a case where the number of hydroxyl groups is limited from the viewpoint of solubility, in case of being used together with a medium such as lubricating oil discussed after.

Examples of the aliphatic amine compound (D) in the low-friction agent composition of the present invention are aliphatic amine compounds each having C<sub>6</sub>-C<sub>30</sub> straight or branched hydrocarbon chains or groups, preferably C<sub>8</sub>-C<sub>24</sub> straight or  
5 branched hydrocarbon chains, more preferably C<sub>10</sub>-C<sub>20</sub> straight or branched hydrocarbon chains. When the carbon number of the hydrocarbon chain is not within the range of 6 to 30, there arises a possibility that the lubricating oil may not produce a sufficient friction reducing effect as expected. It is a matter of course  
10 that other hydrocarbon groups are had if straight or branched aliphatic hydrocarbon groups within the above carbon number range.

Specific examples of the C<sub>6</sub>-C<sub>30</sub> straight or branched hydrocarbon chain include: alkyl groups, such as hexyl, heptyl, octyl, nonyl, decyl, undecyl, dodecyl, tridecyl, tetradecyl, pentadecyl, hexadecyl, heptadecyl, octadecyl, nonadecyl, icosyl, heneicosyl, docosyl, tricosyl, tetracosyl, pentacosyl, hexacosyl, heptacosyl, octacosyl, nonacosyl and triacontyl; and alkenyl groups, such as hexenyl, heptenyl, octenyl, nonenyl, decenyl, undecenyl, dodecenyl, tridecenyl, tetradecenyl, pentadecenyl, 20 hexadecenyl, heptadecenyl, octadecenyl, nonadecenyl, icosenyl, heneicosenyl, docosenyl, tricosenyl, tetracosenyl, pentacosenyl, hexacosenyl, heptacosenyl, octacosenyl, nonacosenyl and triacontenyl.

The above alkyl and alkenyl groups include all possible  
25 straight structures or branched structures. Additionally, the position of double bonds in alkenyl groups is free.

The aliphatic amine compound (D) can be exemplified by various amine compounds and derivatives of these, such as the nitrogen-containing heterocyclic compounds of monoamine,  
30 polyamine, alkanolamine, imidazoline compound and the like each having straight or branched aliphatic hydrocarbon group having the carbon number of 6 to 30.

Monoamine can be concretely exemplified by laurylamine,

lauryldimethylamine, palmitylamine, stearylamine, oleylamine and the like.

Polyamine can be concretely exemplified by stearyltetraethylenepentamine, oleylpropylenediamine and the 5 like.

Alkanolamine can be concretely exemplified by lauryldiethanolamine, dodecyldipropanolamine, oleyldiethanolamine and the like.

The nitrogen-containing heterocyclic compounds are 10 concretely exemplified by N-hydroxyethyloleylimidazolyne and the like.

The derivatives are exemplified by alkylene oxide adducts, acid-modified compounds and the like.

The alkylene oxide adducts are exemplified by compounds 15 which are obtained upon addition of alkylene oxide to nitrogen oxide in the above-mentioned various amine compounds, concretely by N,N-dipolyoxyalkylene-N-alkyl(alkenyl)amines which are obtained upon addition of alkylene oxide to primary monoamine having alkylene group and alkenyl group each having the carbon 20 number of 6 to 28, more concretely N,N-dipolyoxyalkylene-N-oleylamines and the like.

The acid-modified compounds are exemplified by compounds prepared by reacting the above various amine compounds with carboxylic acids (II), preferably the above-mentioned aliphatic 25 monocarboxylic acids (II-1) (more preferably ones having the carbon number of 2 to 30), the above-mentioned aliphatic polycarboxylic acids (II-2) (more preferably ones having the carbon number of 2 to 30, or containing oxalic acid or the like), the above-mentioned carbon-cyclic carboxylic acids (II-3) (more 30 preferably ones having the carbon number of 6 to 30, or containing phthalic acid, trimellitic acid and pyromellitic acid or the like) so as to neutralize or amidate the whole or part of the remaining amino and/or imino groups.

The above-mentioned oxygen-containing compound (C) and aliphatic amine compound (D) are used in a sliding surfaces of the DLC coated sliding member (A) and the sliding member (B), singly (or in an amount of 100 %) as the low-friction agent 5 composition, thereby exhibiting an extremely excellent low friction characteristics. However, as the low-friction agent composition in the present invention one in which other components are blended to the oxygen-containing organic compound (C) and/or the aliphatic amine compound (D) may be used and supplied to the 10 sliding surfaces so as to lubricate the sliding surfaces. As the other components, a medium such as lubricating oil base oil, various additives and the like are exemplified.

The contained amount of the oxygen-containing organic compound (C) or the aliphatic amine compound (D) is not particularly 15 restricted; however, the lower limit of the contained amount based on the total amount (total mass) of the low-friction agent composition is normally 0.001 %, preferably 0.05 %, more preferably 0.1 %, particularly preferably 0.5 % from the viewpoint of friction reduction effect. The upper limit of the contained amount is 100 % 20 as mentioned above. In case that other components, particularly the medium is blended, the upper limit based on the total amount of the low-friction agent composition is normally 50 %, preferably 20 %, more preferably 10 %, particularly preferably 5 % from the viewpoint of solubility to the medium and storage stability. 25 In the present invention, even addition of the oxygen-containing organic compound (C) and/or the aliphatic amine compound (D) in a small amount of about 0.1 to 2 % can exhibit an excellent low friction characteristics. Additionally, if the solubility and storing stability of the aliphatic amine compound (D) to the medium 30 is taken into serious consideration, it is preferable that the upper limit is preferably 3.0 %, more preferably 2.0 %, further preferably 1.4 %.

As the above-mentioned medium, concrete examples are

mineral oil, synthetic oil, natural fat and oil, diluted oil, grease, wax, hydrocarbons having the carbon number of 3 to 40, hydrocarbon solvents, organic solvents other than the hydrocarbon solvents, water and the like, and a mixture of these, and  
5 particularly these in the state of liquid, grease or wax under a sliding condition and at a normal temperature.

As the above-mentioned medium there is particularly preferably employed a lubricating oil base oil (a base oil of the lubricating oil). Such lubricating oil base oil is not  
10 particularly limited and any ordinary base oil, either mineral oil type or synthetic type, for lubricant composition can be employed.

Examples of the lubricating oil base oil of mineral oil type include a product formed by subjecting a lubricant fraction,  
15 obtained as a result of atmospheric distillation or vacuum distillation of crude oil, to at least one of solvent deasphalting, solvent extraction, hydrocracking, solvent dewaxing, hydrorefining and wax isomerization, particularly a base oil subjected to hydrocracking, hydrorefining or wax isomerization.  
20 Among such products, there is preferred a mineral oil obtained by hydrorefining or hydrocracking, or an isoparaffinic mineral oil obtained by isomerization of GTL (gas-to-liquid) wax by a Fischer-Tropsche process or of normal paraffin-rich wax obtained in a dewaxing step of lubricant oil.

25 Examples of the lubricating oil base oil of synthetic type include an alkyl naphthalene, an alkyl benzene, a polybutene and a hydrogenated product thereof; a poly- $\alpha$ -olefin such as a 1-octene oligomer, a 1-decene oligomer, an ethylene propylene oligomer or a hydrogenated product thereof; an isobutene oligomer and a  
30 hydrogenated product of isobutene oligomer; isoparaffin, alkyl benzene, alkyl naphthalene, diester (for example, trimethylpropane ester such as trimethylpropane capryoate, trimethylpropane pelargonate, trimethylolpropane pelargonate,

trimethylolpropane isostearinate and the like; and pentaerythritol ester such as pentaerythritol-2-ethylhexanoate, pentaerythritol pelargonate), polyoxyalkylene glycol, dialkyldiphenyl ether, polyphenyl ether and the like; and mixtures of these. Preferable examples of the synthetic lubricating oil base oil are poly- $\alpha$ -olefin such as 1-octene oligomer, 1-decene oligomer and the like, and hydrogenated product thereof.

In addition to the use of the lubricating oil base oil of mineral oil type or the lubricating oil base oil of synthetic type either singly or as a mixture, it is also possible to use a mixture of two or more kinds of the base oil of mineral oil type or the base oil of synthetic type. Also in such mixture, a mixing ratio of two or more kinds of the base oils is not particularly restricted and can be selected arbitrarily.

A total aromatic content of the lubricating oil base oil is not particularly restricted, but is preferably 15 % or less, more preferably 10 % or less and further preferably 8 %. A total aromatic content in the lubricating oil base oil exceeding 15 % results in an inferior stability to oxidation and is undesirable. A composition of a high friction reducing effect can be obtained even with a total aromatic content in the lubricating oil base oil of 2 % or less, or even 0 %, for example of lubricating oil base oil such as a highly hydrocracking mineral oil, a wax isomerized mineral oil, a poly- $\alpha$ -olefin or a hydrogenated product, a hydrogenated product of 1-decene oligomer, polyole ester, or a mixture thereof. In case the content of the organic oxygen-containing organic compound (C) (excluding esters as the lubricating oil base oil) is higher (for example, at 2 % or higher, since the storage stability may be deteriorated, it is preferable, if necessary, to regulate the total aromatic content (for example at 2% or higher) of the lubricating oil base oil by blending a solvent extracted mineral oil or an alkylbenzene, or to employ

an ester as the lubricating oil base oil, thereby raising the solubility of the oxygen-containing compound (C). The "total aromatic content" means a content of an aromatic fraction measured according to ASTM D2549, and such aromatic fraction ordinarily 5 contains alkylbenzenes, alkynaphthalenes, anthracene, phenanthrene, alkylated substances thereof, a compound in which four or more benzene rings are condensed, and compounds containing heteroaromatic structure such as pyridines, quinolines, phenols and naphthols.

10 Further, the sulfur content in the lubricating oil base oil is not particularly restricted. The sulfur content based on the total amount of the base oil is preferably not more than 0.2 %, more preferably not more than 0.1, further preferably not more than 0.05 %. Particularly, hydrogenated purified mineral oil or 15 synthetic base oil has a sulfur content of not more than 0.005 % or substantially does not contain sulfur (not more than 5 ppm), and therefore these are preferably used as the base oil.

Also the lubricating oil base oil is not particularly restricted in a kinematic viscosity thereof, but in case of use 20 as a lubricant composition for an internal combustion engine, a kinematic viscosity at 100°C is preferably 2 mm<sup>2</sup>/s or higher, and more preferably 3 mm<sup>2</sup>/s or higher. Also an upper limit is preferably 20 mm<sup>2</sup>/s or less, more preferably 10 mm<sup>2</sup>/s or less and particularly preferably 8 mm<sup>2</sup>/s or less. A lubricating oil base 25 oil with a kinematic viscosity at 100°C of 2 mm<sup>2</sup>/s or higher allows to obtain a composition capable of sufficient oil film formation, an excellent lubricating property and a smaller evaporation loss of the base oil under a high temperature condition. On the other hand, a kinematic viscosity at 100°C of 20 mm<sup>2</sup>/s or less reduces 30 a fluid resistance, thereby allowing to obtain a composition with a smaller frictional resistance in a lubricated site. If the kinematic viscosity is less than 2 mm<sup>2</sup>/s, there is the possibility that a sufficient frictional resistance can be obtained while

a vaporizing characteristics is inferior, which is not preferable. If the kinematic viscosity exceeds 20 mm<sup>2</sup>/s, there is the possibility that a low friction characteristics is difficult to be exhibited while a low temperature characteristics are degraded, 5 which are not preferable. In the present invention, a mixture which are prepared by freely mixing two or more base oils selected from the above-mentioned base oils can be used, in which the base oils having the kinematic viscosity (as a single base oil) other than the above-mentioned can be also used as far as the base oils 10 have a kinematic viscosity at 100°C which viscosity is within the above-mentioned preferable range.

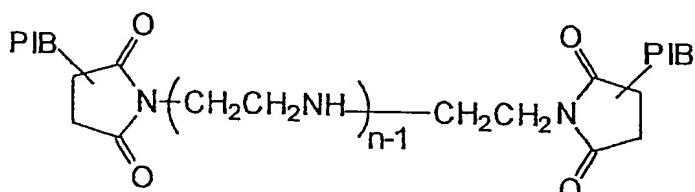
Furthermore, a viscosity index of the lubricating oil base oil is not particularly restricted but is preferably 80 or higher, and, in case of use as a lubricant composition for an internal 15 combustion engine, it is preferably 100 or higher, more preferably 120 or higher, and may be within a range of 140 to 250. A lubricating oil base oil of a high viscosity index allows to obtain a composition excellent not only in a low-temperature viscosity characteristics but also in a less oil consumption, a fuel efficiency 20 characteristics, and a friction reducing effect.

The low-friction agent composition may further include an ashless dispersant, an abrasion preventing agent or an extreme pressure agent, a metal-based detergent, an antioxidant, a viscosity index improver, a friction modifier agent other than 25 (C) and (D), an antirusting agent, a nonionic surfactant, an antiemulsifier agent, a metal deactivator, or a defoaming agent singly or in a combination of plural kinds, for improving required performances.

As the ashless dispersant, various known ashless 30 dispersants can be employed. For example polybutenylsuccinimide or a derivative thereof can be advantageously employed.

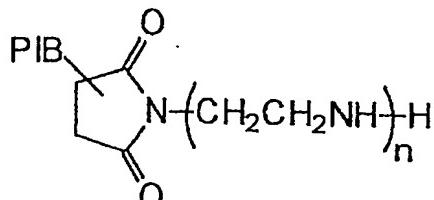
The above-mentioned polybutenyl succinimide include compounds represented by the following chemical formulas (1) and

(2).



(1)

5



(2)

PIB in these chemical formulae represents a polybutenyl group derived from polybutene. The polybutene can be prepared  
10 by polymerizing high-purity isobutene or a mixture of 1-butene and isobutene in the presence of a boron fluoride catalyst or an aluminum chloride catalyst in such a manner that the polybutene attains a number-average molecular weight of 900 to 3,500, preferably 1,000 to 2,000. When the number-average molecular weight of the polybutene is less than 900, there is a possibility of failing to attain a sufficient detergent effect. When the number-average molecular weight of the polybutene exceeds 3,500, the polybutene may undesirably deteriorate in low-temperature fluidity.

20 In each of the chemical formulae, n represents an integer of 1 to 5, preferably 2 to 4, so as to attain a good detergent effect. In the production of the polybutenyl succinimide, the polybutene may be used after purified by removing trace amounts

of fluorine and chlorine residues, which result from the above polybutene production catalyst, by any suitable treatment (such as adsorption process or washing process). The amount of the fluorine and chlorine residues is preferably controlled to 50  
5 ppm or less, more preferably 10 ppm or less, most preferably 1 ppm or less.

The production method of the polybutenyl succinimide is not particularly restricted. For example, the polybutenyl succinimide can be prepared by reacting an chloride of the  
10 above-mentioned polybutene, or the polybutene from which fluorine and chlorine residues are removed, with maleic anhydride at 100 to 200°C to form polybutenyl succinate, and then, reacting the thus-formed polybutenyl succinate with polyamine (such as diethylene triamine, triethylene tetramine, tetraethylene  
15 pentamine or pentaethylene hexamine).

The polybutenyl succinimide derivative can be exemplified by boron- and acid-modified compounds obtained by reacting the polybutenyl succinimide of the formulas (1) and (2) with boron compounds or oxygen-containing organic compounds so as to neutralize or amide the whole or part of the remaining amino and/or imide groups. Among these, boron-containing polybutenyl succinimide, especially boron-containing bis(polybutenyl) succinimide, is preferably used.  
20

The above boron compound can be a boric acid, a borate or  
25 a boric acid ester. Specific examples of the boric acid include orthoboric acid, metaboric acid and paraboric acid. Specific examples of the borate include: ammonium salts including ammonium borates, such as ammonium metaborate, ammonium tetraborate, ammonium pentaborate and ammonium octaborate. Specific examples  
30 of the boric acid ester include: esters of boric acids and alkylalcohols (preferably C<sub>1</sub>-C<sub>6</sub> alkylalcohols), such as monomethyl borate, dimethyl borate, trimethyl borate, monoethyl borate, diethyl borate, triethyl borate, monopropyl borate,

dipropyl borate, tripropyl borate, monobutyl borate, dibutyl borate and tributyl borate. Herein, the content ratio of nitrogen to boron (B/N) by mass in the boron-containing polybutenyl succinimide is usually 0.1 to 3, preferably 0.2 to 1.

5       The above oxygen-containing organic compound can be exemplified by: C<sub>1</sub>-C<sub>30</sub> monocarboxylic acids, such as formic acid, acetic acid, glycolic acid, propionic acid, lactic acid, butyric acid, valeric acid, caproic acid, enanthic acid, caprylic acid, pelargonic acid, capric acid, undecylic acid, lauric acid, 10 tridecanoic acid, myristic acid, pentadecanoic acid, palmitic acid, margaric acid, stearic acid, oleic acid, nonadecanoic acid and eicosanoic acid; C<sub>2</sub>-C<sub>30</sub> polycarboxylic acids, such as oxalic acid, phthalic acid, trimellitic acid and pyromellitic acid, and anhydrides and esters thereof; C<sub>2</sub>-C<sub>6</sub> alkylene oxides; and 15 hydroxy(poly)oxyalkylene carbonates.

The amount of the polybutenyl succinimide and/or the derivative thereof added in the low-friction agent composition is not particularly restricted, and is preferably 0.1 to 15%, more preferably 1.0 to 12%, based on the total amount of the 20 lubricating oil. When the amount of the polybutenyl succineimide and/or the derivative thereof is less than 0.1%, there arises a possibility of failing to attain a sufficient detergent effect. It becomes uneconomical when the amount of the polybutenyl succineimide and/or the derivative thereof exceeds 15%. In 25 addition, such a large amount of the polybutenyl succineimide and/or the derivative thereof tends to cause a deterioration in demulsification ability.

The ashless dispersant other than the above-mentioned can be exemplified by polybutenylbenzylamines and polybutenylamines 30 each having polybutenyl groups of number-average molecular weight of 900 to 3,500, polybutenyl succinimides having polybutenyl groups of number-average molecular weight of less than 900 and derivatives thereof.

As an antioxidant and as an anti-wear agent, various known ones can be blended. For example, it is preferable to contain zinc dithiophosphate represented by the following chemical formula (3) as an antioxidant and as an anti-wear agent.

5



In the chemical formula (3),  $\text{R}^4$ ,  $\text{R}^5$ ,  $\text{R}^6$  and  $\text{R}^7$  each represent  $\text{C}_1\text{-C}_{24}$  hydrocarbon groups. The  $\text{C}_1\text{-C}_{24}$  hydrocarbon group is  
10 preferably a  $\text{C}_1\text{-C}_{24}$  straight-chain or branched-chain alkyl group, a  $\text{C}_3\text{-C}_{24}$  straight-chain or branched-chain alkenyl group, a  $\text{C}_5\text{-C}_{13}$  cycloalkyl or straight-chain or branched-chain alkylcycloalkyl group, a  $\text{C}_6\text{-C}_{18}$  aryl or straight-chain or branched-chain alkylaryl group, or a  $\text{C}_7\text{-C}_{19}$  arylalkyl group. The above alkyl group or alkenyl  
15 group can be primary, secondary or tertiary.

Specific examples of  $\text{R}^4$ ,  $\text{R}^5$ ,  $\text{R}^6$  and  $\text{R}^7$  include: alkyl groups, such as methyl, ethyl, propyl, butyl, pentyl, hexyl, heptyl, octyl, nonyl, decyl, undecyl, dodecyl, tridecyl, tetradecyl, pentadecyl, hexadecyl, heptadecyl, octadecyl, nonadecyl, icosyl, heneicosyl, docosyl, tricosyl and tetracosyl; alkenyl groups, such as propenyl, isopropenyl, butenyl, butadienyl, pentenyl, hexenyl, heptenyl, octenyl, nonenyl, decenyl, undecenyl, dodecenyl, tridecenyl, tetradecenyl, pentadecenyl, hexadecenyl, heptadecenyl, octadecenyl (oleyl), nonadecenyl, icosenyl, heneicosenyl, docosenyl, tricosenyl and tetracosenyl; cycloalkyl groups, such as cyclopentyl, cyclohexyl and cycloheptyl; alkylcycloalkyl groups, such as methylcyclopentyl, dimethylcyclopentyl, ethylcyclopentyl, propylcyclopentyl, ethylmethylcyclopentyl, trimethylcyclopentyl, diethylcyclopentyl,

ethyldimethylcyclopentyl, propylmethylcyclopentyl,  
propylethylcyclopentyl, di-propylcyclopentyl,  
propylethylmethylicyclopentyl, methylcyclohexyl,  
dimethylcyclohexyl, ethylcyclohexyl, propylcyclohexyl,  
5 ethylmethylcyclohexyl, trimethylcyclohexyl, diethylcyclohexyl,  
ethyldimethylcyclohexyl, propylmethylcyclohexyl,  
propylethylcyclohexyl, di-propylcyclohexyl,  
propylethylmethylicyclohexyl, methylcycloheptyl,  
dimethylcycloheptyl, ethylcycloheptyl, propylcycloheptyl,  
10 ethylmethylcycloheptyl, trimethylcycloheptyl,  
diethylcycloheptyl, ethyldimethylcycloheptyl,  
propylmethylcycloheptyl, propylethylcycloheptyl,  
di-propylcycloheptyl and propylethylmethylicycloheptyl; aryl  
groups, such as phenyl and naphthyl; alkylaryl groups, such as  
15 tolyl, xylyl, ethylphenyl, propylphenyl, ethylmethylphenyl,  
trimethylphenyl, butylphenyl, propylmethylphenyl,  
diethylphenyl, ethyldimethylphenyl, tetramethylphenyl,  
pentylphenyl, hexylphenyl, heptylphenyl, octylphenyl,  
nonylphenyl, decylphenyl, undecylphenyl and dodecylphenyl; and  
20 arylalkyl groups, such as benzyl, methylbenzyl, dimethylbenzyl,  
phenethyl, methylphenethyl and dimethylphenethyl.

The above-mentioned hydrocarbon groups include all  
considerable straight or branched chain structures. The position  
of double bond of alkenyl group, the bonding position of alkyl  
25 group to cycloalkyl group and the bonding position of alkyl group  
to aryl group are free.

Specific examples of the zinc dithiophosphate usable  
include zinc diisopropylidithiophosphate, zinc  
diisobutyldithiophosphate, zinc di-sec-butyldithiophosphate,  
30 zinc di-sec-pentyldithiophosphate, zinc  
di-n-hexyldithiophosphate, zinc di-sec-hexyldithiophosphate,  
zinc di-octyldithiophosphate, zinc  
di-2-ethylhexyldithiophosphate, zinc di-n-decyldithiophosphate,

zinc di-n-dodecyldithiophosphate, zinc  
diisotridecyldithiophosphate and mixtures thereof.

The amount of the zinc dithiophosphate added in the lubricating oil is not particularly restricted. The zinc 5 dithiophosphate is preferably contained in an amount of 0.1% or less, more preferably in an amount of 0.06% or less, most preferably in a minimum effective amount, in terms of the phosphorus element based on the total amount of the lubricating oil in order to produce a higher friction reducing effect. When the amount of the zinc 10 dithiophosphate exceeds 0.1%, there arises a possibility of inhibiting the excellent friction reduction effect of the oxygen-containing organic compound (C) at sliding surfaces of the DLC member and various metal materials, particularly iron-based material.

15 The zinc dithiophosphate can be prepared by any known method. For example, the zinc dithiophosphate may be prepared by reacting alcohols or phenols having the above R<sup>4</sup>, R<sup>5</sup>, R<sup>6</sup> and R<sup>7</sup> hydrocarbon groups with phosphorous pentasulfide to form dithiophosphoric acid, and then, neutralizing the thus-formed dithiophosphoric 20 acid with zinc oxide. Herein, the molecular structure of zinc dithiophosphate differs according to the alcohols and the like used as a raw material for the zinc dithiophosphate production.

The other anti-friction agent or extreme-pressure additive can be exemplified by disulfides, sulfurized fats and oils, olefin 25 sulfides, phosphate esters having one to three C<sub>2</sub>-C<sub>20</sub> hydrocarbon groups, thiophosphate esters, phosphite esters, thiophosphite esters and amine salts of these esters.

The metallic detergent can be any metallic-detergent compound commonly used for a lubricating oil. Specific examples 30 of the metallic detergent usable in connection with the present invention include sulfonates, phenates and salicylates of alkali metals or alkali-earth metals; and mixtures of two or more thereof. Examples of the alkali metals include sodium (Na) and potassium

(K), and examples of the alkali-earth metals include calcium (Ca) and magnesium (Mg). In connection with the present invention, sodium and calcium sulfonates, sodium and calcium phenates, and sodium and calcium salicylates are suitably used. The total base 5 number and amount of the metallic detergent can be selected in accordance with the lubricating oil performance required. The total base number of the metallic detergent is usually 0 to 500 mgKOH/g, preferably 150 to 400 mgKOH/g, as measured by perchloric acid method according to ISO 3771 "Determination of base number 10 - Perchloric acid potentiometric titration method". The amount of the metallic detergent is usually 0.1 to 10% based on the total amount of the lubricating oil.

The antioxidant can be any antioxidant compound commonly used for a lubricating oil. Specific examples of the antioxidant 15 usable in connection with the present invention include: phenolic antioxidants, such as 4,4-methylenebis(2,6-di-tert-butylphenol) and octadecyl-3-(3,5-di-tert-butyl-4-hydroxyphenyl)propionate; amino antioxidants, such as phenyl- $\alpha$ -naphthylamine, 20 alkylphenyl- $\alpha$ -naphthylamine and alkyldiphenylamine; and mixtures of two or more thereof. The amount of the antioxidant is usually 0.01 to 5% based on the total amount of the lubricating oil.

The viscosity index improver can be concretely exemplified 25 by: non-dispersion type viscosity index improvers, such as copolymers of one or two monomers selected from various methacrylic acids, and hydrides of the copolymers; and dispersion type viscosity index improvers, such as copolymers of methacrylates (including nitrogen compounds). There may be also used, as the 30 viscosity index improver, copolymers of ethylene and  $\alpha$ -olefins (such as propylene, 1-butene and 1-pentene) and hydrides thereof, polyisobutylenes and hydrides thereof, a hydrogenated copolymer of styrene and diene, a copolymer of styrene and maleic anhydride

and polyalkylstyrenes.

The molecular weight of the viscosity index improver needs to be selected in view of shear stability. For example, the number-average molecular weight of the viscosity index improver  
5 is desirably in a range of 5,000 to 1,000,000, more desirably 100,000 to 800,000, for dispersion or non-dispersion type polymethacrylates; in a range of 800 to 5,000 for polyisobutylenes and hydrides thereof; and in a range of 800 to 300,000, more desirably 10,000 to 200,000 for ethylene/α-olefin copolymers and  
10 hydrides thereof. The above viscosity index improving compounds can be used alone or in the form of a mixture of two or more thereof. The amount of the viscosity index improver is preferably 0.1 to 40.0% based on the total amount of the lubricating oil.

The friction modifier other than the above-mentioned (C)  
15 and (D) can be exemplified by metallic friction modifier such as boric acid ester, molybdenum dithiophosphate, molybdenum dithiocarbamate, molybdenum disulfide and the like.

The rust inhibitor can be exemplified by alkylbenzene sulfonates, dinonylnaphthalene sulfonates, esters of  
20 alkenylsuccinic acids and esters of polyhydric alcohols.

The nonionic surfactant and the deemulsifier can be exemplified by noionic polyalkylene glycol surfactants, such as polyoxyethylene alkylethers, polyoxyethylene alkylphenyleters and polyoxyethylene alkynaphthyleters.

25 The metal deactivator can be exemplified by imidazoline, pyrimidine derivatives, thiadizol, benzotriazole, thiadiazole and the like.

The anti-foaming agent can be exemplified by silicones, fluorosilicones and fluoroalkylethers.

30 In case that these additives are contained in the low-friction agent composition used in the present invention, the contents of them are as follows: The friction modifier other than (C) and (D), the content of the rust inhibitor and demulsifier

can be suitably selected from the range of 0.01 to 5% based on the total amount of the composition; and the content of the metal deactivator can be suitably selected from the range of 0.0005 to 1% based on the total amount of the composition.

5        In the next place, a friction reduction method according to the invention will be detailed.

In such a friction reduction method, between sliding surfaces made of a DLC coated sliding member (A) covered with diamond-like carbon and a sliding member (B) that uses a metal 10 material, a non-metal material or a coated material obtained by coating a thin film on a surface thereof, and an arbitrary combination thereof, a low-friction agent composition is interposed, at least one kind selected from a group consisting of an oxygen-containing organic compound (C) and an aliphatic 15 amine compound (D) being supplied between the sliding surfaces. Thereby, the low friction characteristics of various sliding surfaces can be improved.

Then, a manual transmission according to the invention will be detailed.

20        A manual transmission according to the invention uses the foregoing low-friction sliding mechanism and includes a sliding section formed by coating diamond-like carbon on at least one of sliding surfaces of sliding members that slide each other in the presence of the low-friction agent composition. Thereby, 25 since the friction coefficient of the sliding section is reduced, the seizure resistance and the wear resistance are improved, and, because of low sliding resistance in the various sections, the fuel consumption of an automobile can be improved.

Fig. 1 is a sectional view showing an example of a sliding 30 section in an automobile manual transmission according to the invention. A manual transmission 1 according to the invention includes, in a clutch housing, an input shaft 3 supported freely rotatably by two ball bearings 2a and 2b; and a main shaft 5 supported

freely rotatably by a roller bearing 4a and a ball bearing 4b, to the input shaft a 3-speed input gear 3a and a 4-speed input gear 3b, respectively, being rotatably engaged through needle bearings 2c and 2d, a 5-speed input gear 3c being fixed.

- 5 On the other hand, to the main shaft 5, a 1-speed main gear 5a engaging with a gear 3d formed to the input shaft 3 and a 2-speed main gear 5b engaging with a gear 3e of the input shaft 3, respectively, are rotatably engaged through a needle bearing 4c and a needle bearing 4d attached through a 2-speed bush 6a.
- 10 Furthermore, to the main shaft 5, a 5-speed main gear 5c engaging with a 5-speed input gear 3c of the input shaft 3 is rotatably engaged through a needle bearing 4e attached through a 5-speed bush 6b.

In the manual transmission 1 according to the invention, 15 in a sliding section between an input shaft 3 and a needle bearing 2c of a 3-speed input gear 3a and on a surface on a side of the input shaft 3 in a sliding section between an input shaft 3 and a needle bearing 2d of a 4-speed input gear 3b, a hard carbon thin film can be coated. It goes without saying that a hard carbon 20 thin film may be coated on surfaces of the needle bearings 2c and 2d, and hard carbon coat may be formed on both thereof.

Furthermore, as to the main shaft 5, a hard carbon thin film can be coated on a surface of a main shaft 5 in a sliding section between the main shaft 5 and a needle bearing 4c of the 25 1-speed main gear 5a; and on surfaces of bushes 6a and 6b in a sliding section between a 2-speed bush 6a of the main shaft 5 and a needle bearing 4d and in a sliding section between a 5-speed bush 6b and a needle bearing 4e. In this case as well, on a surface of the needle bearing 4a, 4b or 4e, or on both of sliding surfaces 30 that contact and slide each other, a hard carbon thin coat can be formed.

On inner periphery surfaces of the 3-speed input gear 3a, 4-speed input gear 3b, 1-speed main gear 5a, 2-speed main gear

5b and 5-speed main gear 5c that contact and slide each other with the respective needle bearings 2c, 2d, 4c, 4d and 4e, respectively, a hard carbon coat may be desirably formed as needs arise.

5        In the above, an example is shown where on five sliding sections in total, that is, the 3-speed input gear 3a and 4-speed input gear 3b of the input shaft 3, the 1-speed main gear 5a of the main shaft 5, the 2-speed main gear 5b and the 5-speed main gear 5c, a hard carbon thin film is formed. The hard carbon thin  
10      film may be formed on other sliding sections such as the respective sliding sections of the ball bearings 2a, 2b, 4b and the roller bearing 4a that rotatably support the input shaft 3 and the main shaft 5.

15      Furthermore, the low-friction agent composition used in the manual transmission, when used on a sliding surface with a hard carbon thin film such as DLC, expresses very excellent low friction characteristics. However, in particular, in order to improve performance necessary as a working oil of the transmission, a metal base cleaning agent, an oxidation inhibitor, a viscosity  
20      index improver, other ash-free friction regulator, other ash-free dispersing agent, an abrasion inhibiting agent or an extreme pressure agent, a rust preventive, a nonionic surfactant, an anti-emulsifying agent, a metal deactivator and a defoaming agent, when added singularly or in a combination of several kinds thereof,  
25      can improve necessary performance.

In the next place, a final reduction gear unit according to the invention will be detailed.

The final reduction gear unit according to the invention uses the foregoing low-friction sliding mechanism and includes  
30      a sliding section formed by coating diamond-like carbon on at least one of sliding surfaces of sliding members that slide each other in the presence of the low-friction agent composition. Thereby, since the friction coefficient of the sliding section

can be reduced, the seizure resistance and the wear resistance can be improved, and the sliding resistance of the various sections is low, the fuel consumption of an automobile can be improved.

Fig. 2 is a sectional view showing an example of a sliding section in an automobile final reduction gear unit according to the invention. The final reduction gear unit 20 includes, in a differential carrier (reduction gear box) 22, a drive shaft 23 provided with a drive pinion 23a at a tip end thereof; a differential case 25 to which a ring gear 25a engaging with the drive pinion 23a is fixed and that is rotatably supported by the differential carrier 22 through a side bearing 24; two side gears 26 rotatably supported inside of the differential case 25; and two pinion mate gears 28 that are rotatably supported by a pinion mate shaft 27 inside of the differential case 25 and that engage with the side gears 26, respectively, the drive shaft 23 being rotatably supported by the differential carrier 22 through two roller bearings 29 and connected to a propeller shaft.

In the final reduction gear unit 20, when the propeller shaft is rotated, the rotation is transmitted through the drive pinion 23a and the ring gear 25a to the differential case 25. When a vehicle goes straight ahead, the differential case 25 integrally rotates with the side gear 26 and the pinion mate gear 28, and thereby left and right driving wheel axles rotate at the same speed.

On the other hand, when a vehicle approaches a curve, owing to an increase in the resistance of an inner axle, the side gear 26 and the pinion mate gear 28, respectively, rotate in the differential case 25, the rotation of the inner axle becomes slower, by just that much, the outer axle becomes larger in the rotation speed to enable to smoothly change a direction of the vehicle.

Now, as the sliding members in the final reduction gear unit 20, for instance, a roller 24a and an inner race 24b of a side bearing 24, a differential case 25, a side gear 26, a pinion

mate shaft 27, a pinion mate gear 28 and a washer 30 that interposes between the differential case 25 and the side gear 26 to regulate a backlash can be cited. Sections between an end surface of a roller 24a and an inner race 24b of the side bearing 24, an inner 5 surface and the side gear 26 of the differential case 25, an inner surface and a washer 30 of the differential case 25, a back surface and the washer 30 of the side gear 26, an outer periphery surface and the pinion mate gear 28 of the pinion mate shaft 27, and a back surface of the pinion mate gear 28 and an inner surface of 10 the differential case 25 become sliding sections that slide each other in the presence of the low-friction agent composition for use in the final reduction gear unit. On one of the sliding surfaces of each of the sliding sections such as an end surface of the roller 24a in the side bearing 24, an inner surface of the differential case 25, an outer periphery surface of the pinion 15 mate shaft 27 and a back surface of the pinion mate gear 28, and both surfaces of the washer 30, a hard carbon thin film can be coated. It goes without saying that a hard carbon thin film may be coated on a sliding surface of a counterpart of the sliding 20 surface or on both of the sliding surfaces.

A hard carbon thin film may be coated on other sliding surfaces than the above such as end surfaces of a roller 29a in the roller bearing 29 that supports the drive shaft 23 and one or both of outer periphery surfaces of the inner race 29b.

25 Furthermore, the low-friction agent composition used in the manual transmission, when used on a sliding surface with a hard carbon thin film such as DLC, expresses very excellent low friction characteristics. However, in particular, in order to improve performance necessary as a working oil of the transmission, 30 a metal base detergent, an oxidation inhibitor, a viscosity index improver, other ash-free modifier, other ash-less dispersant, an abrasion inhibitor or an extreme pressure agent, a rust preventive, a nonionic surfactant, an anti-emulsifying agent,

a metal deactivator and a defoaming agent, when added singularly or in a combination of several kinds thereof, can improve necessary performance.

#### EXAMPLES

5 In what follows, the invention will be more detailed with reference to Examples and Comparative Examples. However, the invention is not restricted to the examples.

##### 1. Low-friction sliding mechanism

(Sliding member)

10 As an example of a sliding member, a test piece for use in a simple pinion disc friction test as shown in Fig. 3 was prepared. The simple test piece includes three pins and a disc and is prepared with a sliding member obtained according to a method described below.

###### 15 - Pin material

After polishing into a predetermined pin shape from a heat-treated SUJ2 material, polishing was applied with a lapping tape to finish pins into various surface roughnesses ( $R_a$  is 0.2  $\mu\text{m}$  or less).

###### 20 - Disc material

After disc-like raw materials made of a heat-treated SUJ2 material and an AC2A material were subjected to a predetermined aging process, a sliding surface with a pin was polished, followed by finishing to various surface roughnesses.

###### 25 - Surface treatment

On surfaces of thus prepared pin materials and disc materials, by use of a PVD process or a CVD process that uses graphite as a target, materials (1) through (3) below were coated with various film thicknesses. Coated surfaces were further polished with a lapping tape and finished to various surface roughnesses ( $R_a$  is 0.1  $\mu\text{m}$  or less).

(1) a-C ... (PVD processing)

(2) DLC(a-C:H) ... (CVD processing)

(3) CrN

The sliding members are shown in Table 1.

Table 1

Example	Pin-on-disc Material						Film Thickness (μm)	Surface hardness	Surface roughness Ra (μm)	Sample Oil No.	Friction Coefficient					
	Disc		Pin		Coating											
	Base material	Coating	Base material	Coating	Disc	Pin										
Example 1	Heat-treated SUJ2 Material	a-C	Heat-treated SUJ2 Material	None	1.1	1800	750	0.04	0.05	1	0.034					
Example 2	Heat-treated SUJ2 Material	a-C	Heat-treated SUJ2 Material	a-C	1.1	1.1	1800	1850	0.04	0.03	1	0.029				
Example 3	Heat-treated SUJ2 Material	DLC(a-C:H)	Heat-treated SUJ2 Material	None	2	1650	750	0.03	0.03	1	0.055					
Example 4	Heat-treated SUJ2 Material	DLC(a-C:H)	Heat-treated SUJ2 Material	DLC(a-C:H)	2	1.8	1650	1500	0.03	0.03	1	0.049				
Example 5	ACA2	None	Heat-treated SUJ2 Material	a-C	0.8	80	1550	0.05	0.02	1	0.048					
Example 6	Heat-treated SUJ2 Material	a-C	Heat-treated SUJ2 Material	None	1.5	2550	750	0.05	0.05	2	0.029					
Example 7	Heat-treated SUJ2 Material	a-C	Heat-treated SUJ2 Material	None	0.8	1850	750	0.05	0.05	3	0.055					
Example 8	Heat-treated SUJ2 Material	a-C	Heat-treated SUJ2 Material	None	0.5	1350	750	0.04	0.05	4	0.037					
Example 9	Heat-treated SUJ2 Material	a-C	Heat-treated SUJ2 Material	None	0.5	1350	750	0.04	0.05	5	0.040					
Example 10	Heat-treated SUJ2 Material	a-C	Heat-treated SUJ2 Material	None	1.1	1800	750	0.04	0.05	8	0.015					
Example 11	Heat-treated SUJ2 Material	a-C	Heat-treated SUJ2 Material	None	1.1	1800	750	0.04	0.05	9	0.04					
Example 12	Heat-treated SUJ2 Material	a-C	Heat-treated SUJ2 Material	None	1.1	1800	750	0.04	0.05	10	0.048					
Example 13	Heat-treated SUJ2 Material	a-C	Heat-treated SUJ2 Material	None	1.1	1800	750	0.04	0.03	11	0.052					
Comparative Example 1	Heat-treated SUJ2 Material	a-C	Heat-treated SUJ2 Material	None	1.1	1800	750	0.04	0.05	6	0.14					
Comparative Example 2	Heat-treated SUJ2 Material	a-C	Heat-treated SUJ2 Material	None	1.1	1800	750	0.04	0.05	7	0.098					
Comparative Example 3	Heat-treated SUJ2 Material	PVD/CrN	Heat-treated SUJ2 Material	None	2.0	1.1	1700	750	0.04	0.03	4	0.132				
Comparative Example 4	Heat-treated SUJ2 Material	PVD/CrN	Heat-treated SUJ2 Material	None	2.0	1.1	1700	750	0.04	0.03	2	0.148				
Reference Example 1	Heat-treated SUJ2 Material	PVD/CrN	Heat-treated SUJ2 Material	None	2.0	1.1	1700	750	0.04	0.03	7	0.056				

(Preparation of low-friction agent composition)

- Sample Oil 1

As lubricating oil base oil, hydrogenated 1-decene oligomer (kinematic viscosity at 100°C: 3.9 mm<sup>2</sup>/s, viscosity index: 124 and total aromatic content: 0.0%) was used. Thereto, 1.0% of oleyl alcohol as an oxygen-containing organic compound, 13.0% of other additive (5.0% of ash-less dispersant: polybutenyl succinic imide (nitrogen content: 1.2%), metal base detergent: 0.5% of calcium sulfonate (total base number: 300 mgKOH/g and calcium content: 12.0%) and 0.9% of calcium phenate (total base number: 255 mgKOH/g and calcium content: 9.2%), a viscosity index improver, an oxidation inhibitor, an extreme pressure agent, a rust-preventive, an anti-emulsifying agent, a nonionic surfactant, a metal deactivator, a defoaming agent and the like) were blended to prepare.

- Sample Oil 2

Except that 13.0% of other additive was not added, an operation same as sample 1 was repeated to prepare.

- Sample Oil 3

Except that oleic acid was used as an oxygen-containing organic compound, an operation same as sample 1 was repeated to prepare.

- Sample Oil 4

Except that 0.5% of oleyl alcohol and 0.5% of oleic acid were used as the oxygen-containing organic compound, an operation same as sample 1 was repeated to prepare.

- Sample Oil 5

Except that with hydrocracked mineral oil (kinematic viscosity at 100°C: 5.0 mm<sup>2</sup>/s, the viscosity index: 120 and total aromatic content: 5.5%) as lubricating oil base oil, 1.0% of oleic acid amide was added as an oxygen-containing organic compound, an operation same as sample 1 was repeated to prepare.

- Sample Oil 6

Commercially available engine oil of which kinematic viscosity at 100°C is 10.2 mm<sup>2</sup>/s was used.

- Sample Oil 7

Except that in place of oleic acid amide 1.0% of molybdenum dithiocarbamate was added, an operation same as sample 5 was repeated to prepare.

- Sample Oil 8

Glycerin (Glycol Anhydrous: 1,2,3-Propanetriol, Fluka, manufactured by Sigma Aldrich Japan Co.,) was used singularly (100%).

- Sample Oil 9

A tri-ester (KAOLUBE KSL-268) of trimethylol propane and a mixture of aliphatic acids i-C8, n-C8, C10 and C11 was used singularly (100%).

- Sample Oil 10

Except that 1.0% of glycol monooleyl ether was added as an oxygen-containing organic compound, an operation same as sample 5 was repeated to prepare.

- Sample Oil 11

Glycerol mono-2-ethylhexyl ether was singularly used (100%).

Compositions and sample characteristics of the low-friction agent compositions are shown in Table 2.

Table 2

	Sample oil 1	Sample oil 2	Sample oil 3	Sample oil 4	Sample oil 5	Sample oil 6 <sup>8)</sup>	Sample oil 7	Sample oil 8	Sample oil 9	Sample oil 10	Sample oil 11
Synthetic Oil <sup>1)</sup>	% by mass	100	100	100	-	-	-	-	-	-	-
Mineral oil <sup>2)</sup>	% by mass	-	-	-	100	100	-	-	-	-	100
Oleyl alcohol <sup>3)</sup>	% by mass	1.00	1.00	-	0.50	-	-	-	-	-	-
Oleic acid <sup>4)</sup>	% by mass	-	-	1.00	0.50	-	-	-	-	-	-
Oleyl amide <sup>5)</sup>	% by mass	-	-	-	-	1.00	-	-	-	-	-
Molybdenum compound <sup>6)</sup>	% by mass	-	-	-	-	-	unspecified	1.00	-	-	-
Glycerin <sup>9)</sup>	% by mass	-	-	-	-	-	-	-	100	-	-
Trimethylolpropane ester <sup>10)</sup>	% by mass	-	-	-	-	-	-	-	-	100	-
Glycerol monooleyl ether <sup>11)</sup>	% by mass	-	-	-	-	-	-	-	-	-	1
Glycerol mono-2-ethylhexyl ether <sup>12)</sup>	% by mass	-	-	-	-	-	-	-	-	-	100
Other additive <sup>7)</sup>	% by mass	13.0	-	13.0	13.0	13.0	13.0	13.0	-	-	13.0
Sample oil characteristics:											
Kinematic viscosity (100°C)	mm <sup>2</sup> /s	10.2	3.9	10.2	10.3	10.3	10.2	10.3	Un-measured	5.3	10.2

1) PAO (poly α-olefin) (kinematic viscosity at 100°C: 3.9 mm<sup>2</sup>/s, viscosity index: 124 and aromatic content: 0.0% by mass)  
 2) Hydrocracked base oil (kinematic viscosity at 100°C: 5.0 mm<sup>2</sup>/s, viscosity index: 120 and aromatic content: 5.5% by mass)

3) Oleyl alcohol

4) Oleic acid

5) Oleic acid amide

6) Molybdenum dithiocarbamate (molybdenum content: 9.9% by mass)

7) As other additives, ash-less dispersing agent, a viscosity index improver, an oxidation inhibitor, an extreme pressure agent, a rust-preventive, an anti-emulsifying agent, a nonionic surfactant, a metal deactivator and a defoaming agent are included.

8) Commercially available SG oil

9) Glycerin (Fluka 49707 Glycerol anhydrous: 1,2,3-Propanetriol)

10) Trimethylol propane (trimethylol propane iso-C8, n-C8, C10, 11 ester)

11) Glycerol monooleyl ether

12) Glycerol mono-2-ethylhexyl ether

(Examples 1 through 13)

As shown in Table 1, the respective sliding members were combined, further with the respective low-friction agent compositions (the sample oils 1 through 5 and 8 through 11) described together in Table 1, low-friction sliding mechanisms were prepared, followed by carrying out a pin-on-disc friction test described below. Results thereof are shown together in Table 1.

[Pin-on-disc Friction Test]

Pressure at maximum hertz: 80 MPa

Disc rotation speed: 30 rpm

Oil supply method: oil bath

Temperature of supplied oil: 80°C

Test time period: 60 min

(Comparative Examples 1 through 4)

Similarly to examples, the respective sliding members were combined, further with the respective low-friction agent compositions (the sample oils 1, 2, 6 and 7) described together in Table 1, low-friction sliding mechanisms were prepared, followed by carrying out a pin-on-disc friction test. Results thereof are shown together in Table 1.

From Table 1, it is found that all combinations of the base materials and the sample oils obtained in Examples 1 through 13 show excellent low friction coefficients. For instance, these are, in comparison with Comparative Example 1 where a combination of a base material that is used in a general gasoline engine and sample oil 6 is used, could obtain the friction reduction effect of substantially 50 to 70%.

Furthermore, from results of Examples 6 through 8, it is found that a hydroxyl group in the low-friction agent composition is excellent in the friction reduction effect.

Still furthermore, from results of Examples 10 and 11, it is found that a compound having an alcoholic hydroxyl group is

excellent in the friction reduction effect.

Test pieces obtained in Examples 1 through 11 each did not have any problem in a surface shape after the test, were very excellent in the wear resistance as well, and showed stable low  
5 friction characteristics.

A combination of a test piece base material and a low-friction agent composition according to Reference Example 1 is a combination where steel materials one of which is CrN-treated one and organic molybdenum that is said to be the most effective as the low-friction  
10 agent composition for sliding surfaces between steel materials are combined. As a result, the friction coefficient shows such a low value as substantially 0.06. This is inferred that similarly to a mechanism so far studied in various fields, a molybdenum disulfide film is formed on a sliding surface and thereby low  
15 friction is obtained. In the invention, the low friction is a target, and it is found that the low friction characteristics in the foregoing examples are very excellent.

Furthermore, a combination of the test piece base material and the low-friction agent composition according to Comparative  
20 Example 1 is a combination of general bearing steel and engine oil. As a result, the friction coefficient exceeds 0.1 to be poor in the friction characteristics. This can be assumed that the mechanism showing a low friction behavior suggested in the invention did not sufficiently work.

On the other hand, Comparative Example 2 is a combination where steel materials one of which is DLC-treated and sample oil blended with an organic molybdenum compound are combined. The friction coefficient was such high as substantially 0.1, that is, an advantage such as that of Example 2 was not obtained. This  
30 is inferred that the friction reduction mechanism is different from that of a sliding surface between existing steel materials.

Furthermore, Comparative Examples 3 and 4 are a combination where steel material obtained by applying a CrN treatment on a

base material and used in Comparative Example 2 and sample oil used in the examples, that is, sample oil that can obtain the low friction effect when applied to steel materials one of which is DLC-treated are combined. As a result, the friction  
5 coefficient showed such a large value as exceeding 0.1. It is assumed that since this is a different combination from that of a metal material and sample oil shown in the invention, the lower friction cannot be achieved.

A combination of a test piece base material and a low-friction  
10 agent composition according to Reference Example 1 is a combination where steel materials one of which is CrN-treated and sample oil  
7 where organic molybdenum that was most effective as the low-friction agent composition for sliding surfaces between existing steel materials was blended are combined. As a result,  
15 the friction coefficient shows such a low value as substantially 0.05. This is inferred that similarly to a mechanism so far studied in various fields, a molybdenum disulfide film was formed on a sliding surface and thereby low friction was obtained.

## 2. Manual Transmission

20 As shown in Fig. 4, with a cylinder-like test piece 11 as a sliding side test piece and a disc-like test piece 12 as a counterpart side test piece, a cylinder-on-disc reciprocating friction test was carried out, and, under the conditions shown below, the friction coefficient was measured.

### 25 [1] Friction Test Conditions

Test device: Cylinder-on-disc reciprocating friction tester

Sliding side test piece:  $\phi 15 \times 22$  mm cylinder-like test piece

30 Counterpart side test piece:  $\phi 24 \times 7.9$  mm disc-like test piece

Load: 400N (pressing load of the sliding side test piece)

Amplitude: 3.0 mm

Frequency: 50Hz

Test temperature: 80°C

Measurement time period: 30 min

[2] Preparation of cylinder-like test piece (sliding side)

5 With SUJ2 steel stipulated as high-carbon chromium bearing steel in JIS G4805 as a raw material, a cylinder-like test piece 11 that is a sliding side test piece was machined into the above dimension, followed by finishing to the surface roughness Ra of 0.04μm.

10 [3] Preparation of disc-like test piece (sliding counterpart side)

Similarly, with SUJ2 steel, a disc-like test piece 12 that is a counterpart side test piece was machined to the dimension, after an upper sliding surface was finished to the surface roughness Ra of 0.05 μm, by means of a PVD arc ion type ion plating process, 15 on a surface thereof, a DLC thin film where an amount of hydrogen atoms is 0.5 atomic percent or less, the Knoop hardness Hk is 2170 kg/mm<sup>2</sup>, and the surface roughness Ry is 0.03 μm was deposited at a film thickness of 0.5 μm. In the Reference Example, one that was not coated with the DLC thin film was used.

20 [4] Preparation of low-friction agent composition for use in manual transmission

As a low-friction agent composition for use in a manual transmission, ones where to mineral oil or synthetic oil (PAO: poly- $\alpha$ -olefin (1-octene oligomer)) as base oil, SP (S and 25 P-containing compound with 0.5% by mass of an amine salt of thiophosphoric acid) or ZnDTP (zinc dithiophosphate) extreme pressure agent (1.5% by mass as a compound), the wear resistance agent and an aliphatic ester or aliphatic amine friction modifier were respectively combined were prepared.

30 [5] Test results

The cylinder-like test pieces and disc-like test pieces, and the low-friction agent compositions for use in the manual transmission were combined as shown in Table 3, followed by

measuring the friction coefficients according to a procedure shown above.

Results are shown in Fig. 5.

Table 3

Division	Disc-like test piece		Raw material of cylinder-like test piece	Low-friction agent composition for manual transmission		
	Raw material (DLC thin film)	Hydrogen content (at%)		Base oil	Extreme pressure agent/wear resistant agent	Friction modifier
Example 14	SUJ2 (Yes)	0.5	SUJ2	Mineral oil	SP + ZnDTP system	Fatty ester
Example 15	SUJ2 (Yes)	0.5	SUJ2	Mineral oil	SP system	Fatty ester
Example 16	SUJ2 (Yes)	0.5	SUJ2	Mineral oil	SP + ZnDTP system	Aliphatic amine
Example 17	SUJ2 (Yes)	0.5	SUJ2	Mineral oil	SP system	Aliphatic amine
Example 18	SUJ2 (Yes)	0.5	SUJ2	PAO	SP + ZnDTP system	Fatty ester
Example 19	SUJ2 (Yes)	0.5	SUJ2	PAO	SP system	Fatty ester
Example 20	SUJ2 (Yes)	0.5	SUJ2	PAO	SP + ZnDTP system	Aliphatic amine
Example 21	SUJ2 (Yes)	0.5	SUJ2	PAO	SP system	Aliphatic amine
Comparative Example 5	SUJ2 (No)	-	SUJ2	Mineral oil	SP + ZnDTP system	Fatty ester
Comparative Example 6	SUJ2 (No)	-	SUJ2	Mineral oil	SP system	Fatty ester
Comparative Example 7	SUJ2 (No)	-	SUJ2	Mineral oil	SP + ZnDTP system	Aliphatic amine
Comparative Example 8	SUJ2 (No)	-	SUJ2	Mineral oil	SP system	Aliphatic amine
Comparative Example 9	SUJ2 (No)	-	SUJ2	PAO	SP + ZnDTP system	Fatty ester
Comparative Example 10	SUJ2 (No)	-	SUJ2	PAO	SP system	Fatty ester
Comparative Example 11	SUJ2 (No)	-	SUJ2	PAO	SP + ZnDTP system	Aliphatic amine
Comparative Example 12	SUJ2 (No)	-	SUJ2	PAO	SP system	Aliphatic amine

As obvious from results of Fig. 5, it was confirmed that in examples where a disc-like test piece on a upper sliding surface of which a DLC thin film was deposited was used, in comparison with Comparative Examples where a disc-like test piece on which a DLC thin film was not deposited was used, the friction coefficient was largely lowered.

### 3. Final Reduction Gear Unit

As shown in Fig. 4, with a cylinder-like test piece 11 as a sliding side test piece and a disc-like test piece 12 as a counterpart side test piece, a cylinder-on-disc reciprocating friction test was carried out, and, under the conditions shown below, the friction coefficient was measured.

#### [1] Friction Test Conditions

Test device: Cylinder-on-disc reciprocating friction tester

Sliding side test piece:  $\phi 15 \times 22$  mm cylinder-like test piece

Counterpart side test piece:  $\phi 24 \times 7.9$  mm disc-like test piece

Load: 400N (pressing load of the sliding side test piece)

Amplitude: 3.0 mm

Frequency: 50Hz

Test temperature: 80°C

Measurement time period: 30 min

#### 25 [2] Preparation of cylinder-like test piece (sliding side)

With SUJ2 steel stipulated as a high-carbon chromium bearing steel in JIS G4805 as a raw material, a cylinder-like test piece 11 that is a sliding side test piece was machined into the above dimension, followed by finishing to the surface roughness Ra of 0.04  $\mu\text{m}$ .

#### [3] Preparation of disc-like test piece (sliding counterpart side)

Similarly, with SUJ2 steel, a disc-like test piece 12 that is a counterpart side test piece was machined to the above dimension,

after an upper sliding surface was finished to the surface roughness Ra of 0.05 μm, by means of a PVD arc ion type ion plating process, on a surface thereof, a DLC thin film where an amount of hydrogen atoms is 0.5 atomic percent or less, the Knoop hardness Hk is 5 2170 kg/mm<sup>2</sup>, and the surface roughness Ry is 0.03 μm was deposited with a thickness of 0.5 μm. In the Reference Example, one that was not covered with the DLC thin film was used.

#### [4] Preparation of Low-friction agent Composition for Final Reduction Gear Unit

10 As a low-friction agent composition for use in a final reduction gear unit, ones where to mineral oil or synthetic oil (PAO: poly- $\alpha$ -olefin (1-octene oligomer)) as a base oil, S-base (4% by mass as a compound), SP-base (1.5% by mass as a compound) or borate-base extreme pressure agent (3% by mass as a compound), 15 the wear resistance agent and an aliphatic ester friction modifier are respectively combined were prepared.

#### [5] Test results

The cylinder-like test pieces and disc-like test pieces, and the low-friction agent compositions for use in the final 20 reduction gear unit were combined as shown in Table 4, followed by measuring the friction coefficients according to a procedure shown below.

Results are shown in Fig. 6.

Table 4

Division	Disc-like test piece		Raw material of cylinder-like test piece			Low-friction agent composition for final reduction gear unit		
	Raw material (DLC thin film)	Hydrogen content (at%)		Base oil	Extreme pressure agent/wear resistant agent	Friction modifier		
Example 22	SUJ2 (Yes)	0.5	SUJ2	Mineral oil	S system	Fatty ester		
Example 23	SUJ2 (Yes)	0.5	SUJ2	Mineral oil	SP system	Fatty ester		
Example 24	SUJ2 (Yes)	0.5	SUJ2	Mineral oil	Borate system	Fatty ester		
Example 25	SUJ2 (Yes)	0.5	SUJ2	PAO	S system	Fatty ester		
Example 26	SUJ2 (Yes)	0.5	SUJ2	PAO	SP system	Fatty ester		
Example 27	SUJ2 (Yes)	0.5	SUJ2	PAO	Borate system	Fatty ester		
Comparative Example 13	SUJ2 (No)	-	SUJ2	Mineral oil	S system	Fatty ester		
Comparative Example 14	SUJ2 (No)	-	SUJ2	Mineral oil	SP system	Fatty ester		
Comparative Example 15	SUJ2 (No)	-	SUJ2	Mineral oil	Borate system	Fatty ester		
Comparative Example 16	SUJ2 (No)	-	SUJ2	PAO	S system	Fatty ester		
Comparative Example 17	SUJ2 (No)	-	SUJ2	PAO	SP system	Fatty ester		
Comparative Example 18	SUJ2 (No)	-	SUJ2	PAO	Borate system	Fatty ester		

As obvious from results of Fig. 6, it was confirmed that in examples where a disc-like test piece on a upper sliding surface of which a DLC thin film was deposited was used, in comparison with Comparative Examples where a disc-like test piece on which 5 a DLC thin film was not deposited was used, the friction coefficient was largely lowered.

In the above, Examples and Comparative Examples according to the invention are more detailed; however, the invention is not restricted thereto, and, as far as it is within the gist of 10 the invention, various modifications can be applied.

For instance, the invention can be applied to gear sliding members used in industrial machinery as well.